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## Team SpaceMaster Robotics Team

**University** Spacemaster- 'Joint European Master in Space Science & Technology'
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**Abstract**

Microgravity is a fascinating environment with many and varied applications over the realms of engineering and science. Unfortunately it is not easy to create microgravity on the surface of a planet like Earth. All attempts nowadays are expensive and time consuming. This project tries to show that low gravity can be reached at much lower costs than current approaches (such as parabolic flights or drop towers). However, this project is a feasibility study of the technique that can be used to create a low gravity environment. If this project can demonstrate that the selected approach is working, it can easily be up scaled for larger payloads or longer periods of low gravity.

The approach used in this project is to drop a payload off a high altitude balloon. During the drop the payload is still connected to the balloon's gondola through a tether which is unreeled from an ordinary fishing spinning reel. The drop is decelerated using the internal brake of the fishing reel. As soon as the payload comes to a halt, it is reeled back up to the gondola and is ready for the next drop.

The project's name is reel.SMRT ("real smart"). It is being realized within the BEXUS (Balloon Experiment for University Students) campaign organised and sponsored by the European Space Agency (ESA), the Swedish Space Corporation (SSC) and the Deutsches Zentrum für Luft und Raumfahrt (DLR). The student group designing and building this experiment consists of nine students originating from eight different countries. All of them are currently enrolled in the Erasmus Mundus sponsored SpaceMaster programme.

The reel.SMRT team has finished the design of the mechanical, electrical and software part of the experiment. With this document the design will be presented to a board of experts from ESA, DLR, SSC and SNSB at the Preliminary Design Review (PDR) in order to refine the design and gather feedback. This document will be enhanced further during the development phase of the experiment. Until then the experiment will be reviewed several more times with the aim to lead this exciting experiment to a successful flight on a balloon taking off from Esrange in northern Sweden in the first week of October 2009.

**Acknowledgements**

The reel.SMRT team is grateful for the encouragement and assistance of those that have supported us in our project to date academically, financially and morally.

Such contributors include ESA, SSC and DLR and their personnel who have facilitated this project through the BEXUS programme and enabled the training, financial and technical aid necessary for this project.

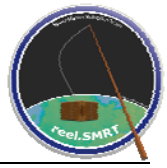
Also Dan Burgess, from Fishing Australia Magazine, who has provided advice in regards to the feasibility of using fishing equipment for a stratospheric balloon experiment, assistance in reel and line selection as relevant to this mission and funding support for these components.

We are grateful to the Delta Utec Tether company, in particularly Michiel Kruijff, who has assisted the team in offering the company's services and testing equipment for a reel.SMRT system analysis. Michiel has also provided useful feedback on the project.

Furthermore, Olle Norvvi, of Airsafe Sweden SB, has provided invaluable assistance in addressing copious parachute and safety related queries, design advice and feedback.

The team is also thankful for the provision of gyroscopes by Prof. Gerndt Reinhard, of Wolfenbüttel University of Applied Sciences.

Last but certainly not least, the team appreciates the input and support of the supervisors at LTU, Alf Wikström and Kjell Lundin, whose feedback is most valuable.

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# 1 INTRODUCTION

The reel.SMRT Project is a mission that shall be launched on a Stratospheric Balloon as part of the BEXUS 8/9 program in October 2009. Through this program, reel.SMRT shall investigate the feasibility of a balloon-based low gravity platform, capable of multiple tests in a single mission. The vision is that the platform may be ultimately up-scaled to provide a viable alternative to parabolic flights and drop towers. The system has the potential to drastically increase the maximum drop lengths of such systems, along with more frequent drops and a greater number of drops in a single balloon mission. The reel.SMRT system also has secondary applications for balloon experimentation. By lowering a capsule, it is possible to take measurements of the atmospheric conditions further from the gondola, increasing the sampling range for sensors. Additionally, the tether can has applications as a safety line for other experiments such as UAV experimentation. This means that the mission, rather than being a purely scientific objective, is an enabler for future experiments. In the upper stratosphere, a balloon that can drop, reel down and reel back up a payload, and perform this multiple times, expands the possibilities for balloon experiments.

A key design driver for the system is its ability to be up-scaled, to eventually be extended to cover distances of hundreds of metres and more. Thus in this investigation, what is tested is the feasibility of such a system. Data obtained from the mission shall be used to evaluate the performance extended over larger scale missions. Therefore, the reel.SMRT system is the initial prototype of the model that has the potential to provide a viable commercial alternative to microgravity experimentation and also a balloon tethered experimental platform.

## 1.1 Document Overview

This document commences with an introduction to the mission, objectives, scientific background and support. The system requirements are defined in Chapter 2. Chapter 3 begins with an introduction to the experimental modes, an overall system description and list of budgets and component lists. The interface definitions are then displayed, followed by the comprehensive descriptions and analysis of subsystem preliminary designs. The preliminary simulation investigation into the system feasibility and performance is also encompassed by this chapter. The reviews and tests are covered in Chapter 4, including the recommendations from the experiment selection workshop, and the subsystem test plans and decision flow chart. Chapter 5 encapsulates the project planning approach including the work breakdown structure, time schedule and resource estimation. Here, the risk management plan is also presented with the most critical risks analysed and addressed. Chapter 6 explains the outreach programme, including tasks to date and future plans. The launch campaign plan is described in Chapter 7, including requests for resources, inputs to the FRP and pre and post

flight activities. The document concludes with a statement of current status of the experiment.

## 1.2 Experiment objectives

The primary objective of the reel.SMRT system is:

Obj.P.1 *To investigate the feasibility of producing a reduced gravity environment on a balloon payload in a recoverable manner and perform this multiple times.*

The secondary objectives of the reel.SMRT system are:

Obj.S.1 *To achieve a versatile line and reel system for increased sampling height range and capability for tether-based applications.*

Obj.S.2 *To educate students about the role and potential of balloon based experiments.*

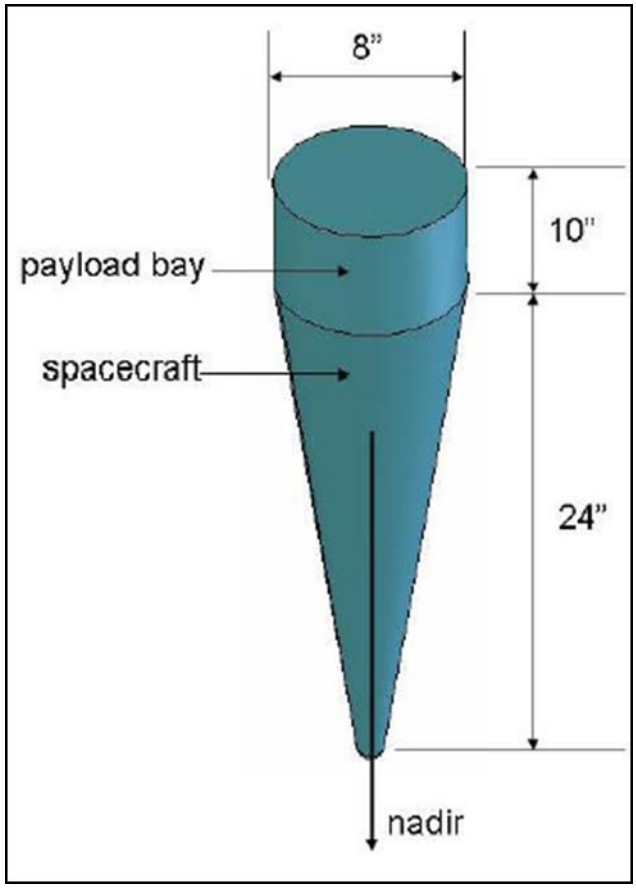
## 1.3 Scientific Background

### 1.3.1 Previous Similar Studies

In order to overcome difficulties of reduced gravity condition testing, reel.SMRT brings together concepts from previous studies and applications. In this way, not only is the project aided by the resources compiled by others but it also highlights the possible applications and the desire of researchers for a system such as reel.SMRT.

#### 1.3.1.1 Capsule Drops from High Altitude Balloons

Much research has been conducted into the possibilities of short reduced gravity periods enabled by dropping from high altitude balloons. A simple dropping capsule has been designed and tested by High Altitude Reduced Gravity Vehicle Experiments (HARVE) (1). This team was able to achieve seven seconds of reduced gravity time from a height of ~24,382 metres. This was without any mitigation of aerodynamic perturbations, similarly to reel.SMRT. A schematic of the HARVE dropped capsule is shown in Figure 1.1.1.



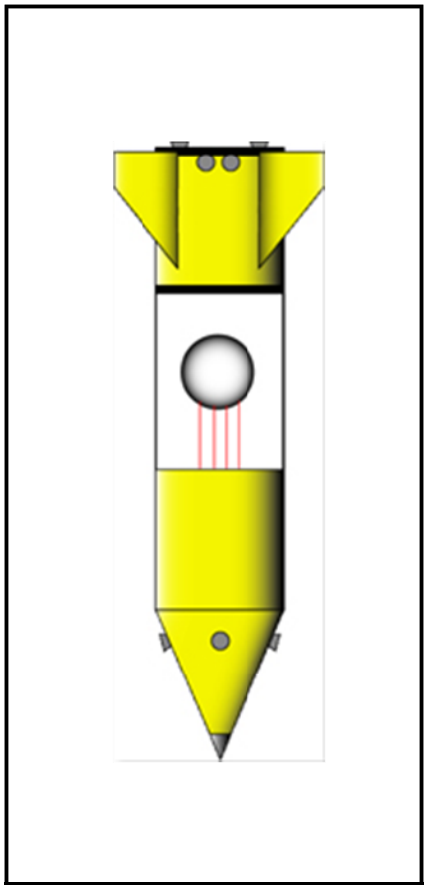



**Figure 1.1.1 Schematic of the HARVE craft (1)**

**Figure 1.1.2 Sawai Lab's Vehicle and Microgravity Experiment Unit (2)**

There are methods to damp these influences upon experiments within modules that are travelling through the upper atmosphere. Similar to the HARVE experiments, Sawai Lab have been conducting tests of a capsule (2) that is able to re-enter the lower atmosphere much like a space-plane. This module is also designed for reduced gravity testing but also has the added feature of perturbation mitigation via the use of a number of gas jets that supports an experiment away from the structure of the dropping body.

1.3.1.2 Reel System

Another experiment that embodies many similarities to the reel.SMRT system was developed by a group of Japanese researchers. This experiment fulfils the same objective to increase the sampling height range of experiments on board high altitude balloons. This system was developed specifically for observing stratospheric vertical microstructures and was a slow reel up and down system (4 reel-down and reel-up cycles of 600m on a high altitude balloon flight) (3). YES2 (4) was an ambitious experiment for students that released a dropped payload to 30 km below an orbiting reel system. Although reel.SMRT is not unreeling to the

same distances, a review of this project has been conducted and useful caveats have been discovered regarding line tension and braking systems.

Two members of SMRT have previously conducted the xgravler experiment (5) onboard the HALE balloon (6) in 2008 . This project had the restriction to use LEGO components and thus was a limited test for a short drop and reel system. xgravler appeared to have ran the experiment during the flight but when data retrieval was conducted, the acceleration data was not found (7).

**Figure 1.1.3: REEL-E Attached to Gondola and REEL Interior Mechanics**

#### 1.3.1.3 Future Applications

Although some microgravity experiments are require longer periods of reduced gravity environment than a drop tower or high altitude balloon drop can produce, nonetheless, there are a number of fields that take advantage of current techniques and could feasibly fly onboard a reel.SMRT system. Short duration fluid effects such as microdroplet production (8), foam attributes (9) and biphasic fluid investigation (10) are applicable. Loosely also within fluid experimentation are the many biomedical studies that undertake microgravity investigation. Combustion experiments which are not allowed on board parabolic flights can use the safety net of the reel.SMRT tether system to still conduct their important research. Biological experiments such as the behaviour of fish in reduced gravity environments (11) can also be conducted on an upscaled version of reel.SMRT. Crystallisation and metallic microstructure formation (12) are also hot topics in the microgravity field and are ideal for short drop testing. reel.SMRT is particularly useful in the above fields because of the possibility for high amounts of repetition of the drops and is an alternative to most drop tower experiments that may not necessarily require the accuracy of drop tower systems.

#### 1.3.1.4 Benefits of the reel.SMRT System

The reel.SMRT system has a number of benefits that make it a viable alternative for microgravity testing in the future. The quality of microgravity expected is not to the level of drop towers or specialist rockets, nevertheless, the dropping of a payload from a balloon gives researchers new opportunities. The versatility of the

system to act as a low gravity platform, sampling platform or safety tether is also an advantage.

*Location Flexibility*

A major benefit of conducting microgravity experiments from balloons is that there are many such locations from which they can be done. High quality drop towers are limited to Fallturm (13) in Bremen, Germany, Micro-Gravity Laboratory of Japan (14) and the three towers (15) (16) (17) run by NASA in the USA. This is particularly of interest to those countries that are not close or do not have access to these facilities such as Australia and the South American nations.

*Availability*

Not only are these drop towers limited to location but availability is a significant issue for many researchers wishing to investigate microgravity effects. High altitude balloons are readily available in many countries (18) and in order to use such a system all that is required is the construction of the reeling system. Following feasibility studies, it is envisaged that such systems could be constructed very quickly and are reusable (unless they are lost or damaged during flight)

*Frequency of drops*

Another issue for many researchers is the number of experiments they can realistically conduct at drop tower locations. For ZARM in Bremen only 15 drops of 4.74 seconds are feasible in a normal weeks operation (13). In order to achieve high levels of microgravity, these facilities must evacuate the chamber of air to reduce air density and as a result, the perturbations on the dropped capsule due to drag. Using a drop and reel system as is being developed by the reel.SMRT team, it would be possible on one flight to conduct more than 100 drops (depending on drop parameters and battery capacity).

*Quality of microgravity*

The simulations currently investigated by reel.SMRT (refer to Section 3.10 'System Simulation') show that it should be possible to see an achievable quality of $10^{-3}$ G's with the reel.SMRT system. Techniques such as using gas jets (2) or other damping techniques to reduce perturbations being transmitted to an experiment from the dropped capsule could be implemented, if required, in further design iterations. In the future, it is hoped that considerable improvement and refinement will be made upon the quality. This compares favourably to the $10^{-2}$ g's and up that are created during parabolic flights (19).

*Environment*

The Stratospheric environment has been singled out as a significant detractor of attempting microgravity experiments from high altitude balloons. Despite this, there are experiments that can actually take advantage of this. Due to the similarities of the stratosphere to the Martian atmosphere some experiments send equipment up on balloons to investigate the effectiveness in such an environment

(20). This can also be taken one step further by reel.SMRT, as the system allows for not only free-fall drops but also descents controlled by reeling down, it is possible to replicate Mars gravity level whilst in the low density atmosphere. It is also possible by controlling this reel down speed to mimic the gravity conditions further from Earth and around other solar bodies.

*UAV tether drops*

A future application upon the scaling up of the reel.SMRT concept will be to tether to experiments wishing to drop from the balloon. This will allow drops of payloads with little to no change compared to an ordinary drop. However, it would be possible over the duration of the balloons flight to drop and recover multiple times; giving experimenters the ability to perform a wider variety of tests or to refine their data. This would be a possibility from lower altitude balloons as well for experiments such as SpaceFish (21) and Icarus (22).

## 1.4 Scientific support

Kjell Lundin and Alf Wikstrom are both supervising this experiment within LTU. They have both spent many years involved in the Space Industry of Kiruna (Esrange, IRF and IRV). Currently they are employed by IRV part time to supervise student projects for balloon and rocket flights (previously including BEXUS(22), REXUS and EXUS launches).

## 1.5 Team Organisation

The reel.SMRT Project team is comprised of nine students from the ‘Erasmus Mundus Joint European Master in Space Science and Technology’, or ‘Spacemaster’. There are three Round 3 members, in their second year of the program and six Round 4 members, in their first year of the program and currently studying at LTU in Kiruna, Sweden.

Each member of the reel.SMRT team is expected to do equal amounts of work to achieve the best outcome for the project. The workload required is dictated by task allocation and so is outcome driven (tasks achieved) rather than time driven (hours per week). The six Round 4 members are enrolled in a 15ECTS point subject at LTU for This Project.

The tasks are delegated to each subsystem from the Project Manager. Within each subsystem, the Subsystem Manager is responsible to the Project Manager for the implementation of their tasks. This means that the Subsystem Managers delegate tasks within their subsystem and ensure their timely completion. The team is structured so that the Subsystem Managers and the Project Manager are all located in Kiruna for ease of communication and control. The structure of the team, and their communication links to the facilitation and support elements, are shown in Figure 1.4.

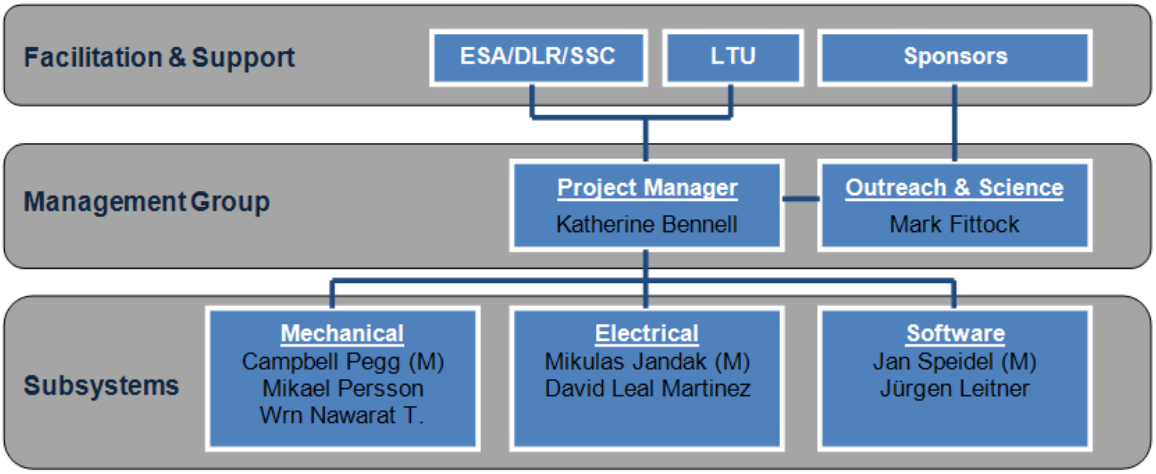



**Figure 1.4 Team Structure for the reel.SMRT Project**

Following the PDR and a more thorough analysis of timeline and task breakdown, two new team members, Mikael and Waen, were added to the mechanical subsystem. This action shall result in a more sophisticated final project that includes a simulation to determine stability and further system performance parameters.

### 1.5.1 Katherine Bennell – Project Manager

**Figure 1.5 Katherine Bennell**

Katherine Bennell, from Australia and the UK, is currently a Round 4 Spacemaster student and the Project Manager for the reel.SMRT project. In 2007 she completed a Bachelor of Engineering in Aeronautical and Space Engineering with Honours as well as a Bachelor of Advanced Science majoring in Advanced Physics at the University of Sydney, Australia. Katherine conducted her Honours thesis on Microcombustion, for which she was published and obtained first place within the school. She has work experience with the Royal Australian Air Force where she worked in the structural team on corrosion and fatigue and also with Sydney University, conducting research on the STEREO space antenna impedance modelling as well as High Redshift Galaxy spectral analysis.

Katherine has a background in management and leadership, with experience in sports, defence and engineering projects. She recently received her commission in the Australian Army at the culmination of a 2 year program, for which she received the Sword of Honour as the course Dux. She was also the Team Leader and Structural subsystem lead for the winning team for the Spacemaster Cansat course. She also was her team leader at the Stuttgart University 2007 Space Station Design Workshop.

As Project Manager, Katherine plans and schedules and directs the project. The planning incorporates the project scope analysis, time and budgets. Key tasks include defining system objectives, estimating work and duration and determining overlapping tasks. Directing involves task delegation to subsystems and delegation of interface responsibilities. This means that Katherine ensures that tasks are performed at a sufficient standard to achieve the project objectives. As such, she also reports on the tasks and runs the bi-weekly meetings where she reviews the progress and completed work and resolves team issues. Katherine also works with Mark Fittock, who is responsible for outreach, in drafting sponsorship applications, monitoring resources and cost budgets. As manager, she also acts as the link between the team and the supporting organisations of ESA, DLR, SSC and LTU.

### 1.5.2 Mark Fittock – Outreach and Science

**Figure 1.6 Mark Fittock**

Mark Fittock, from Australia, holds a Bachelor of Mechanical Engineering with Honours and a Bachelor of Science majoring in Applied Maths and Astrophysics from Monash University. There, he conducted his engineering thesis on stirling engine design and manufacture. Mark has carried out internships at Volvo Aero as a short term engineer, as a BIO-ENVIRO Innovations Technician and as an EarthTeach (Water Department) student engineer. As part of the Round 3 Spacemaster program, Mark was the leader for his Cansat project. He was also involved in the 2008 BEXUS Program as the Mechanical Engineer of the Stratospheric Census team. He is also the Program Manager and Mechanical Engineer for the TREX (Teacup Rocket Experiment) to be flown on MAXUS in 2010.

Mark contributes to the reel.SMRT Project by performing a supporting role for outreach and science. This means that he works in tandem with the Project Manager to organise sponsorship and fundraising for the team, and designs and implements an outreach program. Being responsible for science means that Mark researches the scientific background and justification for the mission and, along with the Project Manager, ensures that the project addresses this background.

### 1.5.3 Campbell Pegg - Mechanical Subsystem (Manager)

**Figure 1.7 Campbell Pegg**

Campbell Pegg, from Australia, is the manager of the Mechanical Subsystem and a student in the Round 4 Spacemaster Program. In 2007, Campbell completed a Bachelor of Aeronautical Engineering with First Class Honours as well as a Bachelor of Advanced Science majoring in Advanced Physics and Advanced Mathematics from Sydney University, Australia. He completed his honours thesis in combustion on droplet evaporation in turbulent flow. Campbell conducted his internship with DLR on rocket propulsion and was his team leader and structures subsystem lead for the Spacemaster Cansat Project. Campbell has also achieved his commission as an officer through the Australian Defence Force, and has since led a platoon of infantry soldiers for two years.

In the reel.SMRT project, Campbell is responsible for the Mechanical Subsystem. This means that he delegates tasks within his subsystem and ensures that they are carried out in a timely manner and to an acceptable standard. Campbell is also directly responsible for the mechanical design, construction and testing of the FISH and line as well as the reel component selection.

### 1.5.4 Mikael Persson – Mechanical Subsystem

**Figure 1.8 Mikael Persson**

Mikael Persson, a Round 4 Canadian and Swedish Spacemaster student, is a graduate from McGill University with an Honours degree in Mechanical Engineering, with a focus on mechatronics, multi-body dynamics, and control systems. His previous work has involved the mechanical design and major contributions to software of a Lunar Excavator for NASA's Centennial Challenges for Regolith Excavation within the McGill LunarEx Team. Also, he has worked on unmanned aerial vehicles in designing the sensor system for pose-estimation, along with the sensor fusion algorithms and the 6 degree of freedom control system.

As a member of the Mechanical subsystem, Mikael's contribution to the team involves the design of the MAIN Payload, including functional and safety elements, the electro-mechanical interfaces, the actuator mechanisms, the reel adaptation and testing, as well as contributions to the theoretical analysis of the dynamics of the FISH.

### 1.5.5 Nawarat Termtanasombat (Waen) - Mechanical Subsystem

**Figure 1.9 Waen**

Waen has a computer engineering degree with First Class Honours from Chulalongkorn University, Bangkok, Thailand. She has experience both within and leading projects including RoboCup soccer robot, RoboCup rescue robot and designing an automotive driving car including the associated programming. This background has imparted Waen with knowledge of multi-body dynamics and modelling.

In the team, Waen is responsible for the simulation of the system. Specifically, she will model the dynamics and kinematics of the FISH, to determine the acceleration and position behaviour. From this, the point at which the reel.SMRT system becomes a viable alternative to drop towers/parabolic flights shall be determined. She shall also investigate the friction in the system and the line. Then, the aerodynamic behaviour of the FISH shall be simulated. These simulation shall build upon an initially simple model, but be upgraded with more factors over time include wind, reel oscillations and gondola perturbation effects. Following the mission, the model shall be improved upon using the mission data. This will enable Waen to more accurately predict the performance of the system over different drop lengths and with variation of parameters.

### 1.5.6 Mikulas Jandak – Electrical Subsystem (Manager)

**Figure 1.10 Mikulas Jandak**

Mikulas is a Round 4 Spacemaster student from the Czech Republic. He holds a bachelors degree in Electrical Engineering and Information Technology, specialising in Cybernetics and Measurement from the Czech Technical University in Prague. Mikulas has much experience in electronics, with experience gained through an internship with the Kolin company.

In the reel.SMRT project, Mikulas is responsible for the Electrical Subsystem. He is the designer of the Electronics for the MAIN Payload in the gondola. This includes the interfacing between the motors and the reel and line guide as well as the design of sensor systems and power supply system. He shall also be responsible for constructing and testing his designs.

### 1.5.7 David Leal Martinez – Electrical Subsystem

**Figure 1.11 David Leal Martinez**

David Leal Martinez, from Mexico, holds a bachelors degree in electronic systems engineering, which is a mixture of computer science and electronics. David is currently studying in TKK as part of the Round 3 Spacemaster program. There, he is conducting his master thesis on reconfigurable robot societies. David also has experience as a hardware and software designer for new products in the traffic industry in Mexico, and also has led a team to create a city wide Wi-Max based network in the city of Morelia. He has also worked for Focusframe, leading a test automation team in Greenpoint Mortgage (now Capital One Bank) in California, USA.

David is a member of the reel.SMRT Electrical Subsystem. In this role, he is responsible for the electronic design, construction and testing of the FISH payload, including the accelerometers and the rest of the sensor suite.

### 1.5.8 Jan Speidel – Software Subsystem (Manager)

**Figure 1.12 Jan Speidel**

Jan Speidel, from Germany, is part of the Round 4 Spacemaster program and is the software subsystem leader. Jan has completed a Diplom-Ingenieur (FH) Computer Engineering, from the Wolfenbüttel University of Applied Sciences, Germany. As part of his Diplom, he conducted his thesis on the research and Development of a conformal taxi-guidance display for head-up applications. Jan gained software design experience in his internship with DLR, where he was involved in programming of software components for DLR's research simulator, for attitude determination in student project 'AVAO-H' (Aerial Vehicle for Autonomous Helicopter Operation) and a group member of the student 'computer vision' project for an Autonomous Model Airship (AVAO-H).

As part of the reel.SMRT team, Jan is responsible for the software subsystem. Jan is the designer of the software modes and microcontroller programming and decision cycles. As subsystem manager, in addition to his design tasks, he has written the subsystem requirements, established the task breakdown and performed the risk analysis for his subsystem.

### 1.5.9 Jürgen Leitner – Software Subsystem

**Figure 1.13 Jürgen Leitner**

Jürgen Leitner, from Austria, is a member of the software subsystem. Jürgen has a Bachelor of Science in Software and Information Engineering from the Technical University of Vienna. As part of his Round 3 Spacemaster course, Jürgen is currently in Japan for three months conducting his thesis on multi-robot cooperation for space applications at the Intelligent Space Systems Laboratory of the University of Tokyo. Jürgen has experience with software and balloon systems, having worked on the reel.E project as part of the HALE program in 2008.

In his role as a supporting member of the Software Subsystem, Jürgen is responsible for assisting with both the communications protocol and ground station design and programming.

## 1.6 Funding support

IRV is the prime funding organisation of the reel.SMRT experiment. Six of the team members are enrolled in the Masters level project course (15 ECTS) and the funding is linked to the successful completion of objectives within this subject above and beyond the requirements of BEXUS. The funding available is 5,000 sek for expenditure on products that must be ordered from Swedish companies.

# 2 MISSION REQUIREMENTS

This chapter includes the definition of all requirements to achieve the mission objectives of the reel.SMRT Project. Mission Level and Subsystem Level requirements are presented and justified. Within these categories, the functional, technical and operational requirements are listed. The functional requirements define how well the system must perform to meet its objectives, whilst the technical requirements determine how the system operates (23). Operational requirements involve qualitative and quantitative parameters that specify the desired capabilities of the system and serve as a basis for determining the operational effectiveness and suitability of the system prior to launch. These operational requirements drive the functional requirements (23). This mission is constrained primarily by the BEXUS User Manual (24) requirements and safety requirements as dictated by ESA and EuroLaunch. Sources from which the requirements were derived include the scientific parameters relating to the mission profile. The requirements are written so as to neither dictate nor impose needless constraints on design, but rather specify what is necessary to perform a successful mission as well as operate the system (23). Each requirement is numbered such that it is trackable and referable throughout the design process.

Within these boundaries, the Primary and Secondary Objectives shall be achieved. It is from these high level system requirements that the subsystem level requirements are derived. The high level (mission level) requirements and their derivations are expressed in Section 2.1. Sections 2.2 to 2.4 describe the requirements for each subsystem.

## 2.1 Mission Level Requirements

### 2.1.1 Mission Level Functional Requirements

The reel.SMRT system shall:

Req.F.1 Achieve an acceleration performance of the FISH to a gravity of less than $10^{-2}$g for at least 2 seconds, in the x, y and z directions.
*Response to Obj.P.1. This acceleration value is similar to the performance of zero-G flights.*

Req.F.2 Drop a payload to a distance of at least 50m, return it to the gondola and repeat this action.
*Response to Obj.P.1.*

Req.F.3 Lower a payload to a distance of at least 50m and return it to the gondola, and repeat this action.
*Response to Obj.P.2.*

Req.F.4 Supply the ground station with periodic feedback sensor data for analysis at the ground station.
Req.F.5 Have a total weight of no more than 25kg.
Req.F.6 Have a total volume of no more than $0.2m^2$.
Req.F.7 Survive atmospheric temperature (possibly 226K) for the mission duration.
Req.F.8 Receive commands from and transmit to the ground station.
Req.F.9 Investigate the feasibility of the system as a reduced gravity environment platform for drops of longer duration.
Req.F.10 Assess the drift of the FISH during a drop and its consequences on the whole system and the measurement accuracy.
Req.F.11 Realise an outreach program.
*In accordance with the Terms and Conditions of the BEXUS Program.*

The reel.SMRT system should:

Req.F.12 Achieve an acceleration performance of the FISH to a gravity of less than $10^{-6}$g for at least 2 seconds, in the x, y and z directions.
*Response to Obj.P.1: $10^{-6}$g is the performance of drop towers.*
Req.F.13 Have a total weight of no more than 20kg.

### 2.1.2 Mission Level Technical Requirements

The reel.SMRT system shall:

Req.T.1 Implement a reel-based mechanism.
Req.T.2 Provide an intrinsic power source within the FISH and the MAIN Payload.
*In accordance with BEXUS Manual* (24) *power supply capacity.*

### 2.1.3 Mission Level Operational Requirements

The reel.SMRT system shall:

Req.O.1 Determine the acceleration performance of the FISH to an accuracy of at least $10^{-2}$g in the x, y and z directions.
*To determine Req.F.1*
Req.O.2 Involve no unmitigated risks with a risk analysis value greater than 15.
Req.O.3 Implement a parachute within the FISH as a safety mechanism.
*To achieve Req.O.2*
Req.O.4 Implement a reel-based mechanism to lower and raise the FISH.
*To achieve Req.F.3*
Req.O.5 Communicate between the FISH and MAIN Payload.

Req.O.6 Implement both an automated and drop-on-command ability for the FISH.

Req.O.7 Operate for the expected lifetime of 5 hours mission duration.

Req.O.8 Shall ensure compliance with the requirements of the BEXUS User Manual.
*In accordance with the Terms and Conditions of the BEXUS Programme.*

Req.O.9 Comply with the overall project schedule and any requests made by ESA, SNSB or EuroLaunch in relation to the execution of the project.
*In accordance with the Terms and Conditions of the BEXUS Programme.*

Req.O.10 Inform EuroLaunch immediately in the case of a problem in the experiment that may affect its performance, impact the schedule or have safety implications.
*In accordance with the Terms and Conditions of the BEXUS Programme.*

Req.O.11 Not exceed the maximum project budget of 4000 EUR.

The reel.SMRT system should:

Req.O.12 Determine the acceleration performance of the FISH to an accuracy of $10^{-6}$g in the x, y and z directions.
*To determine Req.F.12*

## 2.2 Mechanical Subsystem Requirements

### 2.2.1 Mechanical Subsystem Functional Requirements

The reel.SMRT Mechanical Subsystem shall:

Req.F.M.1 Release the FISH into free-fall.
*Response to Req.F.1 and Req.F.2*

Req.F.M.2 Safely bring the FISH to a halt.
*Response to Req.F.2*

Req.F.M.3 Recover the payload to the initial state in preparation for another drop.
*Response to Req.F.2*

Req.F.M.4 Simulate the aerodynamics stability of the FISH.
*Response to Req.F.9*

Req.F.M.5 Predict the level of friction in the line system.
*Response to Req.F.9*

Req.F.M.6 Simulate the position of the FISH.
*Response to Req.F.9*

Req.F.M.7 Limit the mass of the FISH to 1.5kg.
*Response to Req.F.5*

Req.F.M.8 Limit the mass of the MAIN Payload to 23.5kg.
*Response to Req.F.5.*

Req.F.M.9 Have vertical FISH dimension of no more than 0.4m.
*Response to Req.F.6.*

Req.F.M.10 Impart shock forces of no more than 200N magnitude transferable through the gondola.
*Response to Req.O.2 and Req.O.8*

Req.F.M.11 Design the FISH to be dynamically stable.
*Response to Req.F.1.*

### 2.2.2 Mechanical Subsystem Technical Requirements

The reel.SMRT Mechanical Subsystem shall:

Req.T.M.1 protect the payload from mission physics and thermal hazards
*Response to Req.O.2, Req.O.7 and Req.F.M.1*

Req.T.M.2 be able to reduce the velocity of the drop payload to a safe value for all mission scenarios.
*Response to Req.O.2 and Req.O.7.*

Req.T.M.3 adhere to the allocations received in the team budgets

The reel.SMRT Mechanical Subsystem should:

Req.T.M.4 Ensure redundancy in all main functions.
*Response to Req.O.2.*

### 2.2.3 Mechanical Subsystem Operational Requirements

The reel.SMRT Mechanical Subsystem shall:

Req.O.M.1 Include the drop payload in the total volume.
*Response to Req.F.7.*
Req.O.M.2 Implement the GPS with an open sky view.

The reel.SMRT Mechanical Subsystem should:

Req.O.M.3 Minimise aerodynamic drag on the payload.
*Response to Obj.P.1 and Req.F.1*
Req.O.M.4 Minimise pulling tension in the tether during the drop.
*Response to Obj.P.1 and Req.F.1*
Req.O.M.5 Maintain the stability of the FISH on all six degrees of freedom.
*Response to Obj.P.1, Req.F.1 and Req.O.2.*

## 2.1 Electrical Subsystem Requirements

### 2.1.1 Electrical Subsystem Functional Requirements

The reel.SMRT Electrical Subsystem shall:

Req.F.E.1 Implement Analogue to Digital converters capable of providing resolution below noise level of both accelerometers and gyroscopes in both the FISH and the MAIN Payload.
*Response to Req.F.12*

Req.F.E.2 Measure acceleration without insignificant delay with respect to the time of the drop.
*Response to Req.F.12*

Req.F.E.3 Implement ADC capable of providing numerous samples of acceleration and rotation in both FISH and the MAIN Payload.
*Response to* Req.F.4

Req.F.E.4 Be capable of being provided with status data of the FISH during the entire drop.
*Response to* Req.F.4

The reel.SMRT Electrical Subsystem should:

Req.F.E.5 Implement ground station which is to be provided with status data of both FISH and the MAIN Payload.
*Response to* Req.F.4

Req.F.E.6 Implement external memory which should be easy to remove from the MAIN Payload and the FISH.

Req.F.E.7 Be capable of monitoring the position of the FISH in the lower and upper part of the MAIN Payload.
*Response to Req.F.4*

Req.F.E.8 Determine the relative position between inertial sensors of the MAIN Payload and the FISH.
*Response to Req.F.9*

Req.F.E.9 Be capable of synchronizing the acquisition systems on the FISH and on the MAIN Payload.
*Response to Req.F.9*

Req.F.E.10 Implement microcontroller capable of controlling motors.
*Response to Req.F.2*

Req.F.E.11 The operation status of the main motor shall be monitored.
*Response to Req.F.4*

Req.F.E.12 Be able to monitor the battery status.
*Response to Req.F.4*

Req.F.E.13 Implement separated acquisition system and the power electronic.

Req.F.E.14 Monitor the position of the bail.
*Response to Req.F.4*

Req.F.E.15 Implement microcontroller capable of monitoring the status of the FISH, status of the motors and position of the bail in real time.
*Response to Req.F.4*

Reg. F.E.16 Be turned on and off by user and the current power status should be visible.

### 2.1.2 Electrical Subsystem Technical Requirements

The reel.SMRT Electrical Subsystem shall:

Req.T.E.1 Implement AD Converter on the fish and the main payload capable of sampling the acceleration in x, y and z axis at the data rate of more or equal 1000 samples per second.
*Response to Req.F.E.3*

Req.T.E.2 Implement AD Converter on the fish and main payload with resolution of more or equal 16 bits.
*Response to Req.F.E.1*

Req.T.E.3 Measure the acceleration of less than 10mg.
*Response Req.F.1*

Req.T.E.4 Implement accelerometer with the bandwidth of more than 100Hz.
*Response to Req.F.E.2*

Req.T.E.6 Implement the communication capable of communicating in the range of more than 70m.
*Response to Req.F.E.4*

Req.T.E.7 Implement the external memory on both fish and the main payload to be bigger than 64MB.
*Response to Req.F.S.2*

The reel.SMRT Electrical Subsystem should:

Req.T.E.8 Implement switch for turning on and off the both main payload and the fish.
*Response to Reg. F.E.16*

Req.T.E.9 Be equipped with LED to indicate on/off status and the status of the communication between fish and main payload.
*Response to Reg. F.E.16*

### 2.1.3 Electrical Subsystem Operational Requirements

The reel.SMRT Electrical Subsystem shall:

Req.O.E.1 Implement battery on the main payload capable of providing energy for at least 20 drops and for the operational time of 5 hours
*Response to Req.O.7*

Req.O.E.2 Implement sensor package having redundancy to reduce single point of failure
*Response to Req.O.2*

Req.O.E.3 Implement battery pack capable of providing the motors with sufficient current
*Response to Req.O.7*

Req.O.E.4 Implement battery pack capable of fulfilling safety requirements
*Response to Req.O.8*

Req.O.E.5 Implement GPSs capable of operating at the altitude of 40000m

Req.O.E.6 Implement motor capable of operating in the thin atmosphere.
*Response to* Req.O.4

## 2.2 Software Subsystem Requirements

### 2.2.1 Software Subsystem Functional Requirements

The reel.SMRT Software Subsystem shall:

Req.F.S.1 Control the experiment.
*Subsystem objective and purpose*

Req.F.S.2 Store sensor data during flight for post-processing
*The sensor data shall be analysed post-flight to demonstrate the low gravity performance of the system.*

Req.F.S.3 Guarantee emergency procedures in case of mechanical or electrical failure.
*Response to requirement Req.O.7; the* FISH *must not pose a threat to people on the ground or the other balloon payloads.*

The reel.SMRT Software Subsystem should:

Req.F.S.4 Allow uplink and downlink capability to monitor the experiment during the mission.
*A ground station to experiment link provides the ability to react to unforeseen flight behaviour, or drop-on-command as desired.*

### 2.2.2 Software Subsystem Technical Requirements

Req.T.S.1 The reel.SMRT Software subsystem should be based on a real-time operating system (ROTS).
*Many tasks during the experiment are highly time critical. A RTOS ensures a maximum execution time for each task.*

Req.T.S.2 adhere to the allocations received in the team budgets.

### 2.2.3 Software Subsystem Operational Requirements

The reel.SMRT Software Subsystem shall:

Req.O.S.1 Control the actuators and motors during the flight.
*At absolute minimum, one slow reel and one free-fall experiment shall be conducted.*

Req.O.S.2 Detect software faults and recover from them using watchdog and Power-on-reset functionality.
*The Watchdog detects hang-ups of the programme and restarts the microcontroller if necessary, enabling the system to recover from the malfunction.*

The reel.SMRT Software Subsystem should:

Req.O.S.3 Maintain operation of FISH even if FISH-payload communication is lost.
*The mission objective is still able to be achieved even if the communication link fails, if the FISH is recovered such that data is extracted.*

# 3 EXPERIMENT DESCRIPTION

In this chapter the experiment is presented with justifications. The chapter commences with an experiment overview, with a summary of key components and budgets for mass, volume, power and data. The interfaces between subsystems and to the gondola are then defined, with distinct responsibilities established. Finally, the design for each individual subsystem is expounded upon and evaluated.

## 3.1 Experiment overview

To achieve the objectives, the reel.SMRT system has been designed that consists of three primary segments: a ground station, the MAIN Payload and the dropped payload, which is known as the 'Free-falling Instrument System Housing' or FISH. A system diagram comprised of these segments is shown in Figure 3.1.

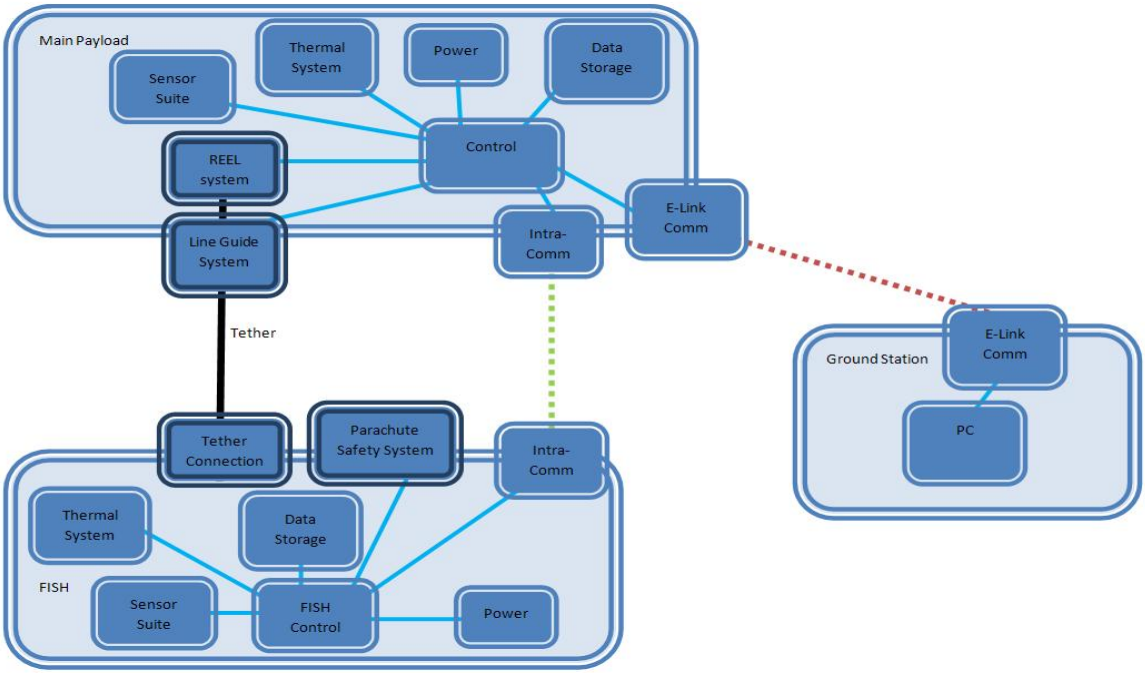



**Figure 3.1 reel.SMRT system diagram**

The MAIN Payload is nested in the balloon gondola and consists of the REEL system, sensor suite, thermal system, power unit, intra communication link and data storage. There is also the E-link communication to the ground for uplink of command and downlink of housekeeping data. The REEL system forms the mechanical interface with the FISH. It consists of a reel, motors, servo motors and a line guide.

The process of dropping the FISH and reeling it up again is called a CATCH. The intra communication between the FISH and the MAIN Payload is called a SMRT KISS. A SMRT KISS takes place for the duration of each CATCH, with the data from the FISH being both stored within it and transferred to the MAIN Payload via Bluetooth ZigBee (IEEE 802.15.4) for back up storage and then downlink. The FISH is a 1.2kg vessel with its own power, thermal system, data storage, sensor suite and parachute. All sensors and controller used both on the MAIN Payload and FISH are the same component, to ensure correct sensor calibration and data validity. A simplified system representation is depicted in Figure 3.2.

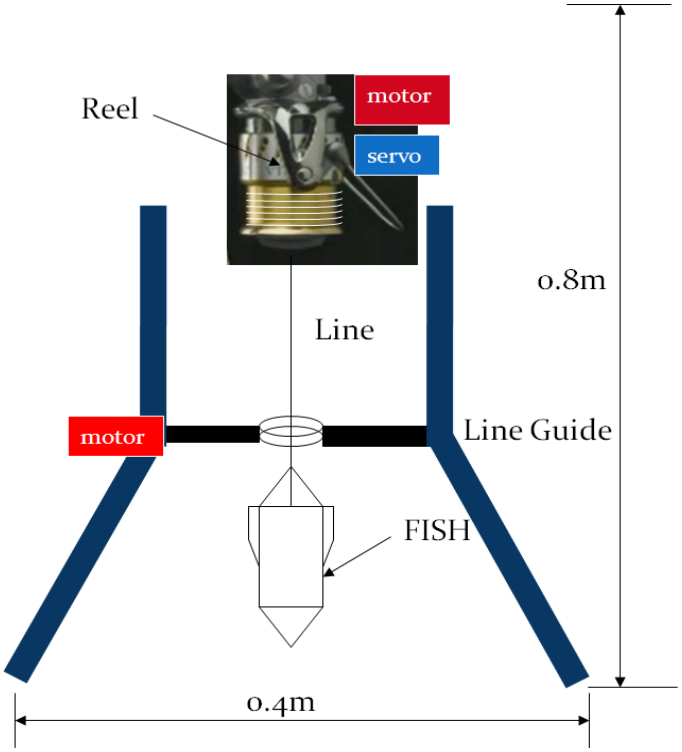



**Figure 3.2 Simplified System Representation**

Therefore, the primary components necessary to support and fulfil the objectives and requirements of the mission are:

- Reel
- Braking system
- High Strength Line
- Safety system: parachute, line guide
- Motors
- Sensors to measure acceleration and position of the FISH for sufficient accuracy matching to the requirements

- Communications hardware between the FISH and the MAIN Payload on the gondola, between the MAIN payload and the gondola and between the gondola and the ground station
- Control System
- Data Storage
- Power Supply
- Thermal System

## 3.2 Modes

The system has been designed to have a free-fall distance of 50m, and a total reel distance of 70m: large enough to obtain relevant data for the feasibility investigation and small enough to simplify the design. The reel.SMRT system shall test two modes to achieve the objectives of the mission: a Drop Mode that aims to produce minimal gravity conditions, and a slow reel mode, for tethered applications such as data sampling over a height range or tethered experiments. The reel up time for each drop is approximately 2 minutes. The number of samples during each mode is 1000 per second for each sensor due to the high accuracy required over the short time of the drop. The time between each drop and slow reel modes shall be a minimum of two minutes for data transfer, and may be longer if required or the motors are determined to be overheating.

### 3.2.1 Drop Mode

The Drop Mode has three phases: free-fall phase, deceleration phase, recovery phase. These phases are depicted in Figure 3.3. In the free-fall phase, the FISH begins inside the MAIN Payload. The line guide is then unlocked and the bale mechanism is released, enabling the FISH to fall under gravity as the line spools off the reel. Once 50m is reached then the bail mechanism shall be shut by turning the motor on the reel handle. This ends the free-fall phase. In the deceleration phase, the brake is applied automatically by the bail closing and the FISH is decelerated to at halt over approximately 20m. Then, the recovery phase begins. In the recovery phase, the FISH will be reeled up back into the MAIN Payload to complete the CATCH. If necessary, the line locking mechanism may be applied between CATCHs, by spinning the line guide using a motor to create a friction lock.

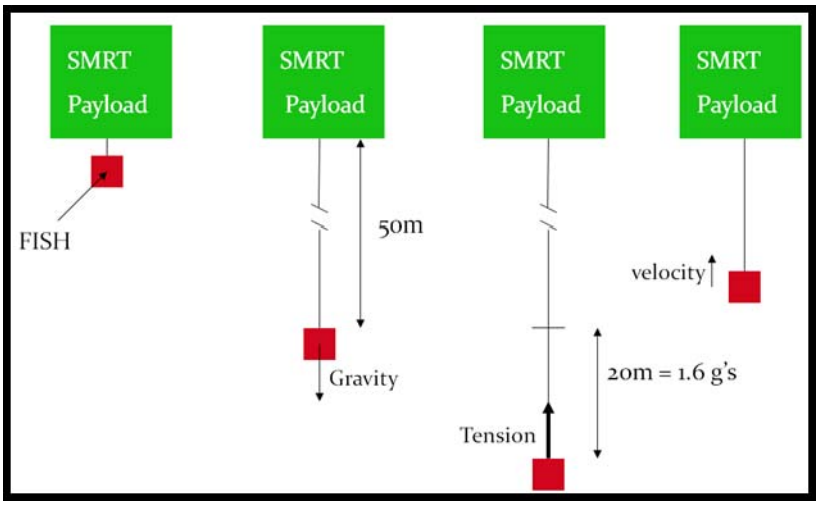



**Figure 3.3 Drop Mode**

Figure 3.4 displays the decision tree for the drop mode. During the drop the behaviour of all relevant feedback sensors is monitored. If any malfunction occurs the emergency recovery mode is activated. This mode helps to bring the experiment into a safe state to allow the recovery of the experiment.

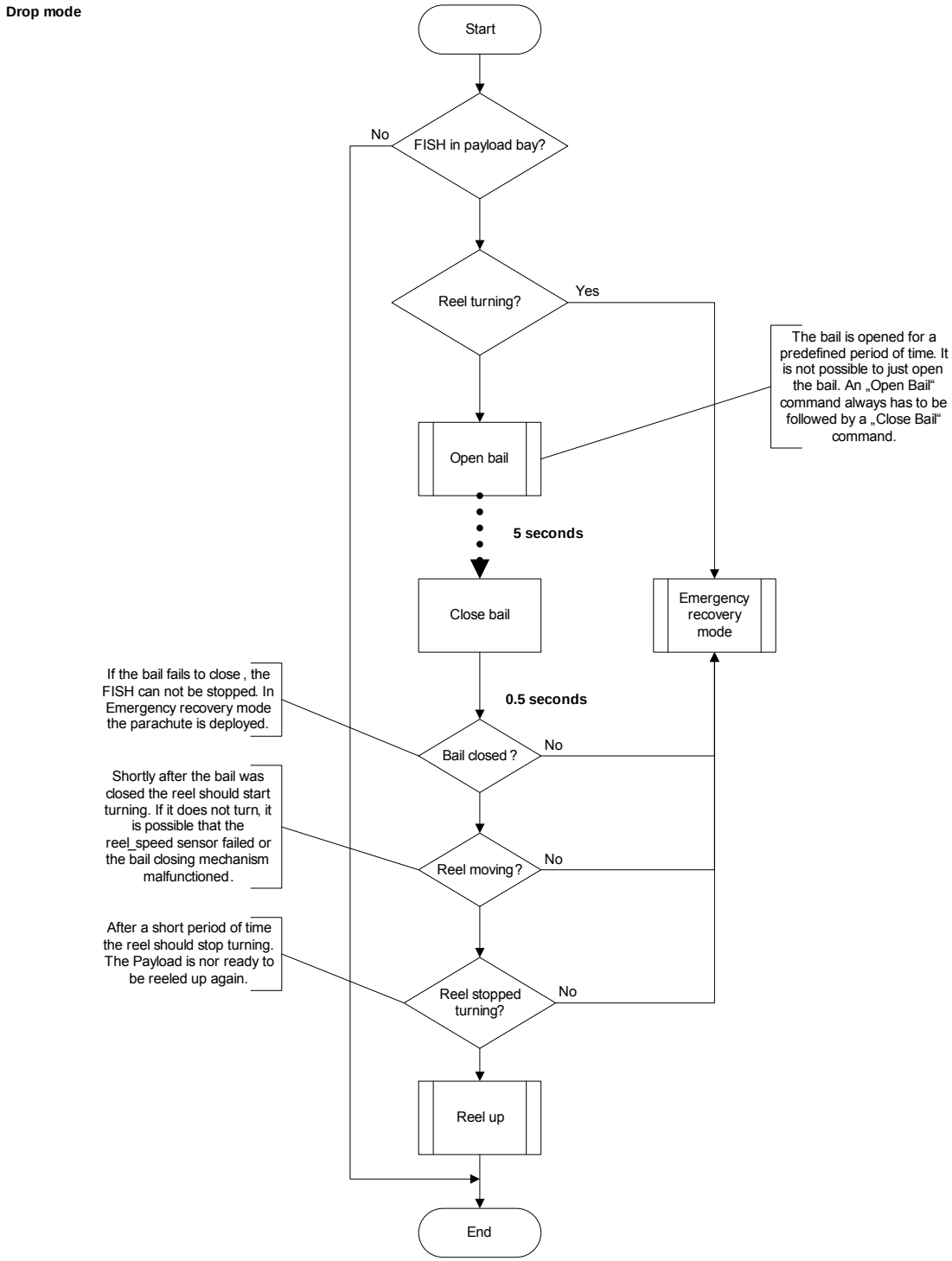

Drop mode
Start
FISH in payload bay?
No
Reel turning?
Yes
The bail is opened for a predefined period of time. It is not possible to just open the bail. An „Open Bail“ command always has to be followed by a „Close Bail“ command.
Open bail
5 seconds
Close bail
Emergency recovery mode
If the bail fails to close , the FISH can not be stopped. In Emergency recovery mode the parachute is deployed.
0.5 seconds
Bail closed ?
No
Shortly after the bail was closed the reel should start turning. If it does not turn, it is possible that the reel_speed sensor failed or the bail closing mechanism malfunctioned.
Reel moving?
No
After a short period of time the reel should stop turning. The Payload is nor ready to be reeled up again.
Reel stopped turning?
No
Reel up
End

**Figure 3.4 Drop Mode Diagram**

### 3.2.2 Slow Reel Mode

The Slow Reel Mode is similar to the Drop Mode but with the free-fall phase replaced by the reel-down phase. The Slow Reel Mode is depicted in Figure 3.5. In the reel-down phase the bail mechanism remains closed. The FISH then is lowered by using the motor to reel down the line by rotating the handle forward, or by dragging the line off the reel if so desired. In this way, the speed of the reeling and the tension in the line may be varied as applicable for the application. The distance of the FISH from the gondola in the slow reel mode is limited only by the length of the line. By lowering the FISH a further distance, information may be obtained about the perturbation effects and stability of the FISH on the end of the long tether.

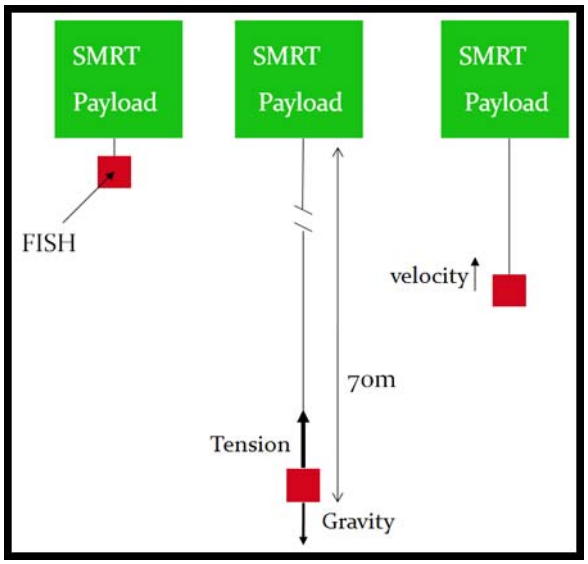



**Figure 3.5 Slow Reel Mode.**

**Note that 70m is the minimum distance that the FISH shall be lowered to in this mission.**

Figure 3.6 shows the decision tree of the slow reel mode. Again, during the reeling process the relevant sensors are monitored carefully. In case of a sensor malfunction, the system enters the emergency recovery mode to reach a predefined state and to allow a safe recovery of the FISH without posing a threat to humans on the ground.

**Slow reel mode**

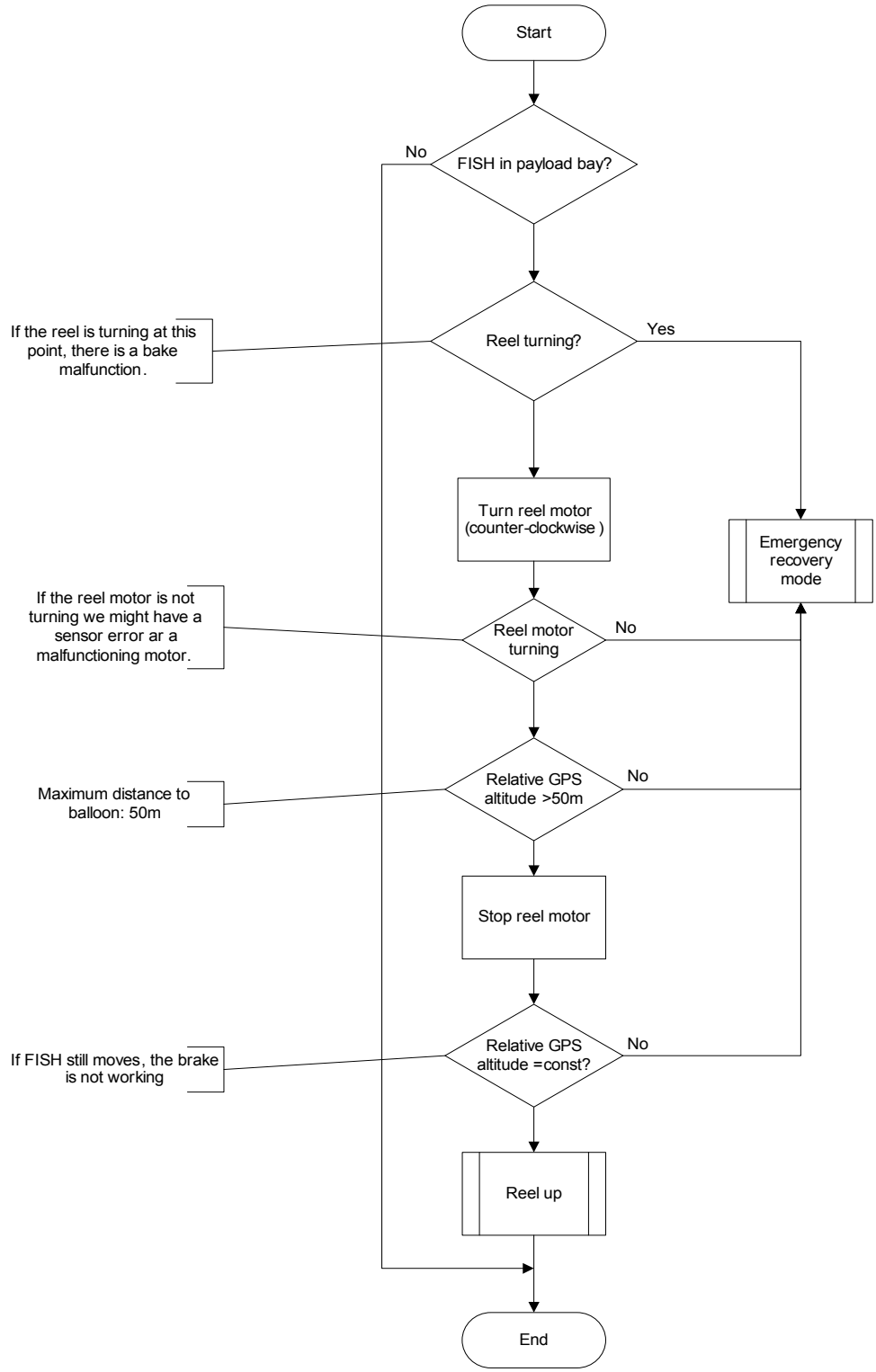

Start
FISH in payload bay?
No
Reel turning?
Yes
If the reel is turning at this point, there is a bake malfunction.
Turn reel motor (counter-clockwise )
Emergency recovery mode
If the reel motor is not turning we might have a sensor error ar a malfunctioning motor.
Reel motor turning
No
Relative GPS altitude >50m
No
Maximum distance to balloon: 50m
Stop reel motor
Relative GPS altitude =const?
No
If FISH still moves, the brake is not working
Reel up
End

**Figure 3.6 Slow Reel Mode Diagram**

## 3.3 Mission Operations

### 3.3.1 Sequence

3.3.1.1 Power-safe mode

Before the launch the reel.SMRT experiment is set to power-safe mode. When in this mode, almost all active components of the experiment are switched off. Only the GPS of the main payload, the pressure sensor on the FISH, and one temperature sensor are still powered. These sensors are needed to monitor the active heating of the electronics bay on the main payload. The GPS and the pressure sensor are needed to detect a possible break of the tether (which is assumed to be possible at any time). If a high sink rate in combination with a fast increase of ambient pressure is detected, the parachute deployment is activated. During the power-safe mode, the communication links from the ground to the main payload and further to the FISH are fully functioning. This allows the operator on the ground to perform tests or even start to work on contingencies if malfunctions are already noticeable in this early stage of the flight.

3.3.1.2 Checkout of all sensors

As soon as the free-float segment of the balloon flight is reached (detected by a decrease of vertical speed from both the GPS and the pressure sensor) the experiment is powered up. That includes all sensors and the second GPS. A test packet is transmitted to the ground station with values from all sensors on board to find out if they all work properly. If not, an alternate procedure can be activated from the ground.

3.3.1.3 Checkout of actuators and the FISH's GPS

Next, all actuators are checked out. The FISH will be reeled down until it has left the payload bay completely. That allows testing the performance of the proximity sensors inside the payload bay that detect the position of the FISH when reeled up into the MAIN payload. The FISH is then slowly reeled down further into a position where the GPS of the FISH can receive the GPS satellites. By doing so, the performance of the GPS can be verified.

3.3.1.4 Test reel up sequence

Now the FISH is reeled up again to check if the reel up algorithm works as expected. The reel up sequence is stopped according to the proximity sensor data inside the main payload.

At this point all necessary checkouts are accomplished. The reel.SMRT is now ready for the first slow reel.

3.3.1.5 First slow reel mode

The first slow reel will be the slowest one of the flight. Its purpose is to test the performance of the motors (thermal aspect) and the feedback sensors both from

the reel and the reel motor. If a sensor is not working properly another sensor can be used and the experiment can be executed as planned. For example by using the altitude data from the GPS on the FISH, this can replace the reel's speed sensor but in lower resolution.

If the performance of the experiment, especially the motor, is as expected, the slow reel up can be executed. During the way up, the reeling process will be stopped to demonstrate the ability to take sensor values at different altitudes. As soon as the FISH is back in the payload bay the data transfer performance can be analyzed in aspect of average data rate and maximum transfer range.

If all tests went well to this point, then the first drop mode test can be executed.

#### 3.3.1.6 First drop mode

If all sensors and actuators are working as expected, the drop can be initiated. This drop will be a regular one for about 2 seconds. At the end of each CATCH, the temperature of the reel motor is verified. If the motor temperature is too high, the next drop will be delayed.

The sequence of the experiments can be chosen freely. However, since the experiment is normally executed by an automatic sequencer, a preset sequence is used. This sequence is most probably a drop followed by a slow reel. Then a short break is probably necessary to transfer all sensor data from the FISH to the payload. The drops can be repeated as often as necessary. However, the limiting factors are the duration of the balloon in free-float, the temperature of the reel motor, the degradation of the brake and the size of the ~~flash~~ memory storage.

Before the gondola is cut off from the balloon the FISH has to be reeled up and stowed in the payload bay. As soon as the GPS and the pressure sensor detect a high sink rate over an extended period of time, the reel.SMRT experiment is put into power-safe mode again with only the essential sensors still being ~~still~~ powered on. This time however, the high bandwidth accelerometer on the FISH that measures acceleration in the z-direction is kept active. It is then possible to detect the impact of the gondola. After impact detection, the experiment shuts itself down completely in order to minimize the risk of short circuits in case the gondola lands on a wet surface.

### 3.3.2 Tether break scenario

If during the experiments the tether ~~should~~ may break and get loose, the GPS altitude sensor and the pressure sensor on the FISH will detect ~~that~~ the situation by~~(~~ considering high sink rate for more than 5 seconds and~~,~~ significantly increasing of the pressure~~)~~. This triggers the deployment of the parachute which ~~will~~ can decrease the sink rate so that the FISH does not pose a threat to living creatures on the ground. If the electronics on the FISH survives after the impact, ~~,~~ it is possible to constantly transmit the GPS position data via the ZigBee to support the recovery team in finding the FISH.

### 3.3.3 Power-On-Reset

In case of a temporary power loss or if a microcontroller had to restart, ~~this function~~ Power-On-Reset function is executed first to bring the experiment into a safe state, ~~–~~independently from~~of~~ the time that the reset occurred ~~(~~even during a drop~~)~~. With this function, it is possible to recover the experiment at any time without risking the mission or safety. The diagram showing the power on reset procedure is shown in Figure 3.7.

**Power-On-Reset (POR)**
(This sequence is executed after startup and if a controller reset (initiated by the watchdog) is executed

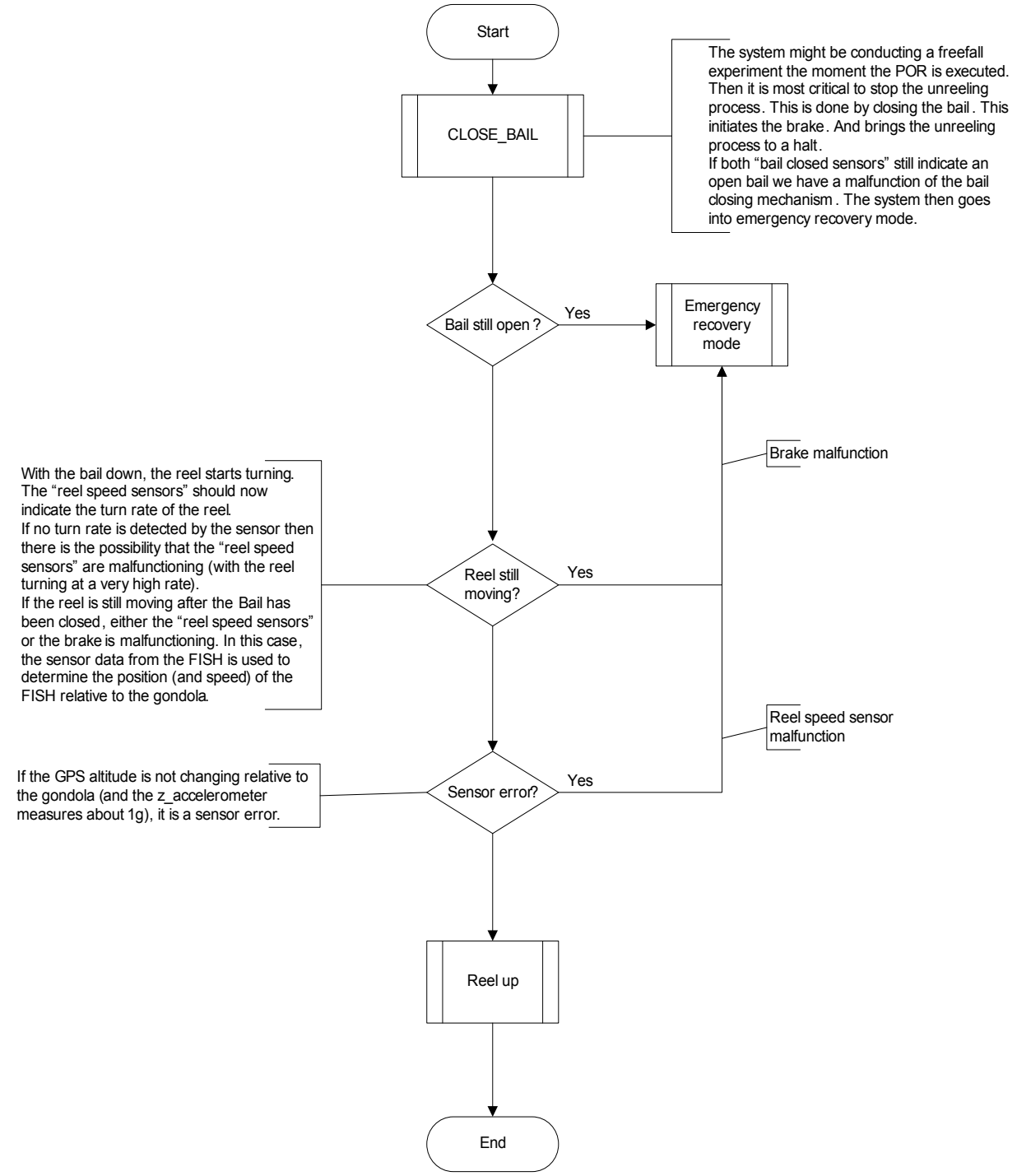

Start
CLOSE_BAIL
The system might be conducting a freefall experiment the moment the POR is executed. Then it is most critical to stop the unreeling process. This is done by closing the bail. This initiates the brake. And brings the unreeling process to a halt.
If both "bail closed sensors" still indicate an open bail we have a malfunction of the bail closing mechanism. The system then goes into emergency recovery mode.
Bail still open ?
Yes
Emergency recovery mode
Brake malfunction
With the bail down, the reel starts turning. The "reel speed sensors" should now indicate the turn rate of the reel.
If no turn rate is detected by the sensor then there is the possibility that the "reel speed sensors" are malfunctioning (with the reel turning at a very high rate).
If the reel is still moving after the Bail has been closed, either the "reel speed sensors" or the brake is malfunctioning. In this case, the sensor data from the FISH is used to determine the position (and speed) of the FISH relative to the gondola.
Reel still moving?
Yes
Reel speed sensor malfunction
If the GPS altitude is not changing relative to the gondola (and the z_accelerometer measures about 1g), it is a sensor error.
Sensor error?
Yes
Reel up
End

**Figure 3.7 Power On Reset diagram**

### 3.3.4 Component List

The main components are summarised in Table 3.1. An in-depth Component list is situated in Appendix A3.

| Components | Material | Source | Description |
|---|---|---|---|
| **Mechanical Subsystem** | | | |
| **MAIN Payload** | | | |
| Universal Profiles PU25 - 350 mm, 300 mm, 100mm | Al. 6061 | Solectro PU25 | Aluminum profile extrusions of 350 mm long |
| Mounting Crown | Al. 6061 | Custom Machined | 30 degree angled crown which is used to connect the top of the profile pyramid and mount most of the payload's components |
| Daiwa Saltiga Surf Spinning Reel 6000 | Mg Alloy | Daiwa | Dual full time infinite anti reverse<br>Machined Aluminium spool<br>Air metal magnesium body treated for saltwater use |
| Reel Motor | Various | Oriental Motors USA<br>AXH230KC-15 | Brushless Motor<br>30 W output<br>6.7 to 167 rpm<br>14.1 lb-in rated torque |
| Line Guide Motor | Various | Oriental Motors USA<br>BLH230KC-5 | Brushless Motor<br>30 W output<br>20 to 600 rpm<br>4.7 lb-in rated torque |
| Servo Motor | Various | Hitec<br>HS-645MG | HS-645MG STANDARD DELUXE<br>HIGH TORQUE SERVO |
| Batteries | Li-Ion | - | High Power Polymer Li-Ion Pack:<br>22.2v 2200mAh<br>22.2 (25.2 peak)<br>Maximal discharge 40A |
| Line Guide | Al. 6061 | Custom Machined | Fork which is powered and enables emergency braking and reeling |
| **FISH** | | | |
| Parachute | TBC | Airsafe, Sweden | Stored in 0.1-0.15 L, has one main attachment to structure, side deployment, reduces velocity of payload |
| Dyneema Braided Line | Dyneema | Platypus | 500 m, 1000N force |
| Swivel | TBD | TBD | TBD |
| **Electrical Subsystem** | | | |
| Accelerometer Colibrys | | Farnell | Accelerometer |
| ADR445 B grade | | Farnell | |
| TMP275 | | Farnell | Temperature Sensor |
| LIS3L02AQ3 | | Farnell | |
| ADC1253 | | Farnell | Analogue - Digital converter |

| | | | |
|---|---|---|---|
| ZigBee | | Farnell | |
| Phoenix GPS Receiver | | DLR | |
| Batteries | | Farnell | |

**Table 3.1 Summarised Component List**

### 3.3.5 Mass Budget

The mass budget has been summarised in Table 3.2. These are the main constraining masses of the system which take into account all components necessary to construct the system. A detailed budget listing these components is displayed in Appendix A2. The total mass of the experiment is 16.4kg with the FISH at 1.13kg.

| Selected Component | Qty | Mass per Item (g) | Mass total (g) | Confidence (%) |
|---|---|---|---|---|
| **MAIN Payload** | | | 15027.364 | |
| Daiwa Saltiga Surf Spinning reel | 1 | 530 | 530 | 90 |
| Reel Motor | 1 | 4000 | 4000 | 70 |
| Line Guide Motor | 1 | 4000 | 4000 | 70 |
| **FISH** | | | 1138.34 | |
| Struts | 3 | 51.65 | 154.95 | 90 |
| Parachute | 1 | 200 | 200 | 70 |
| Fins | 3 | 7.69 | 23.07 | 90 |
| Batteries | 4 | 25.00 | 100.00 | 80 |
| **Line** | | | 220 | |
| Dyneema Braided Line | 1 | 200 | 200 | 80 |
| Swivel | 1 | 10 | 20 | 70 |
| **Total (g)** | | | **16 380** | |

**Table 3.2 Summarised Mass Budget of the system**

### 3.3.6 Volume Budget

The volume budget is summarised in Table 3.3 for the key design constraining components of the reel.SMRT system.

| Component | x (mm) | y (mm) | z (mm) | Volume ($mm^3$) |
|---|---|---|---|---|
| **MAIN Payload** | 400 | 400 | 800 | 128,000,000 |
| Reel | 100 | 110 | 80 | 880,000 |
| Reel Motor | 60 | 60 | 76 | 273,600 |
| Line Guide Motor | 60 | 60 | 76 | 273,600 |
| Line Guide | 14 | 40 | 120 | 35,059 |
| Servos | 40.6 | 19.8 | 37.8 | 30,387 |
| Battery | 106 | 46 | 35 | 170,660 |
| **FISH** | D 150 | | 275 | 4,859,651 |
| Electronics | D 70 | | 50 | 192,423 |
| Batteries | D 26.5 | | 18 | 9,928 |
| Parachute | 80 | 60 | 40 | 192,000 |
| GPS | 70 | 47 | 16 | 52,640 |

**Table 3.3 Volume Budget of Important Components**

Overall the MAIN Payload will be 0.4x0.4x0.8 m, with a combined volume of 0.128 $m^3$. The FISH will be housed in the MAIN Payload thus it will require any more volume in the Gondola.

### 3.3.7 Data Budget

The critical components concerning the data budget are:

- The mass memory (SD-Card) on the FISH
- The mass memory (SD-Card) on the main payload
- The communication link between Fish and main payload (ZigBee)
- The communication link between main payload and ground station (Ethernet/E-Link)

During reeling experiments a huge amount of variety sensors data collected at a high rate. Therefore the peak data rate will occur during the slow reel mode or free fall mode and shortly after that. Table 3.4 shows the bit rates of each set of

sensors and the total data rate that can occur during reeling on the main payload as well as on the FISH.

| Component | No. | Sampling time [1/s] | Resolution [Bit] | Data Budget [kBit/s] |
|---|---|---|---|---|
| **MAIN Payload** | | | | 113.34 |
| Accelerometers | 4 | 1000 | 16 | 64.0 |
| Gyroscopes | 3 | 1000 | 16 | 48.0 |
| Temperature sensors | 5 | 1 | 16 | 0.08 |
| Proximity sensors | 3 | 20 | 1 | 0.06 |
| Hall sensors | 3 | 20 | 10 | 0.6 |
| Reel velocity sensors | 4 | 100 | 1 | 0.4 |
| Current measurement sensor | 1 | 20 | 10 | 0.2 |
| **MAIN Payload** | | | | 180.766 |
| Accelerometers (high precision, low bandwidth) | 3 | 1000 | 24 | 72.0 |
| Accelerometers (low precision, high bandwidth) | 3 | 1000 | 12 | 36.0 |
| Gyroscopes | 3 | 1000 | 24 | 72.0 |
| Temperature sensors | 9 | 1 | 24 | 0.216 |
| Pressure sensor | 1 | 10 | 10 | 0.1 |
| GPS(lat/lon/alt/spd/hdg) | 5 | 1 | 10 | 0.05 |
| Reel velocity sensors | 4 | 100 | 1 | 0.4 |

**Table 3.4 Data Budget**

During the entire flight a maximum of 20 reeling experiments will be performed each lasting approximately 10 seconds during the drop. During that time the amount of data generated is

$$20 \cdot 10s \cdot \left( 113.34 \frac{kBit}{s} + 180.766 \frac{kBit}{s} \right) = 58.8212 \text{MBit}$$

When no experiments are executed and the balloon is in the free float phase the sensors still collect data but at a much lower rate (about 100 times less). This reduces the total data budget of the fight significantly. With an expected free float time of up to 3 hours, the maximum amount of data generated when not performing a reeling experiment is:

$$3 \cdot 60 \cdot 60 \cdot \left( 113.34 \frac{kBit}{s} + 180.766 \frac{kBit}{s} \right) \cdot \frac{1}{100} = 31.763448 \text{MBit}$$

This gives the results in a total of 90.584648 Mbit of sensor data generated during the entire flight.

All sensor data generated on board the FISH will be stored on the local SD-Card and transmitted to the main payload at the same time. On the SD-Card which is located on the main payload both the sensor data received from the FISH as well as the locally collected data will be stored. That amounts is :

$$\frac{58.8212 \text{MBit}}{8} = 7.35265 MByte \quad \text{on the FISH and}$$

$$\frac{31.763448 \text{MBit}}{8} + 7.35265 MByte = 11.323081 \text{MByte}$$

This amount of data is stored on the memory cards on board the FISH and the main payload.

### 3.3.8 Power Budget

The fish power consumption and battery properties are analyzed in

| Batteries | Voltage(V) | Current(Ah) | Number of units | Total Power (Wh) |
|---|---|---|---|---|
| SAFTLSH 14 "Light" | 3.67 | 3.6 | 2 | 26.424 |
| Total amount of current | | | 250mA | |
| The power supplied by the batteries | | | 3600mAh | |
| so the system could be running for about | | | 14.4 Hour | |

Table 3.5.

| Unit | Current Consumption (mA) | At voltage (V) | Power (mW) | Power dissipation (mW) | Units | sum (mW) |
|---|---|---|---|---|---|---|
| Microprocesor | 125 | 3.3 | 412.5 | 1500 | 1 | 412.5 |
| Colibry M8002.D | 0.4 | 5 | 2 | 0 | 3 | 6 |
| ADS1274 | 50 | 5 | 250 | 285 | 1 | 250 |
| ADS1274 | 18 | 3.3 | 59.4 | 0 | 1 | 59.4 |
| ADS1274 | 0.15 | 1.8 | 0.27 | 0 | 1 | 0.27 |
| HMC6352 | 1 | 3.3 | 3.3 | 0 | 1 | 3.3 |
| LIS3L02AQ3 | 0.85 | 3.3 | 2.805 | 0 | 1 | 2.805 |
| Xbee | 45 | 3.3 | 148.5 | 0 | 1 | 148.5 |
| | | | | | Total | 882.775 |

| Batteries | Voltage(V) | Current(Ah) | Number of units | Total Power (Wh) |
|---|---|---|---|---|
| SAFTLSH 14 "Light" | 3.67 | 3.6 | 2 | 26.424 |
| Total amount of current | | | 250mA | |
| The power supplied by the batteries | | | 3600mAh | |
| so the system could be running for about | | | 14.4 Hour | |

**Table 3.5 The power consumption of the fish**

The power budget of the MAIN Payload is driven mainly by the consumption of the main motor. Since the other electronic is to be similar to the electronic in the FISH (peak current of 250mA) and the switching power supply of 24V/5V which further reduces the current consumption, the power consumption of the motor (24V/60W) is much higher than the electronic. So the electronic consumption can be neglected.

The power supply for the Main Payload is 22.2V/4400mAh polymer li-ion battery pack which could support up to 56 minutes of operation of fully loaded motor.

## 3.4 Experiment setup

### 3.4.1 System

As shown in Figure 3.8, the overall system for this experiment consists of a main payload which is rigidly attached to the gondola as well as a drop payload, referred to as the FISH, which is held in the main payload in the initial state of the experiment. The FISH is dropped from the main payload using a reel system, a *Daiwa Saltiga Surf Spinning* fishing reel, which is capable of letting the FISH go into free-fall with minimal resistance from the line. The reel is controlled by an electric motor which will be able to reel the FISH back up into the main payload after a drop and perform the slow reeling down of the FISH for taking measurements at various heights below the gondola. The braking of the FISH after a free-fall drop is also controlled by the same electric motor by using the built-in feature of fishing reels which automatically set the brake back on after the first turn of the handle after a cast. The releasing of the FISH into free-fall is achieved through turning the bail, with the help of two redundant servo-motors, to release the line completely. As a redundant safety system, a line guide is installed which is intended to operate in case of failure in the reel system. The line guide is a simple winch which is powered by an electric motor and is able to perform the basic operations of braking, reeling up, and reeling down, but no free-fall drop of the payload.

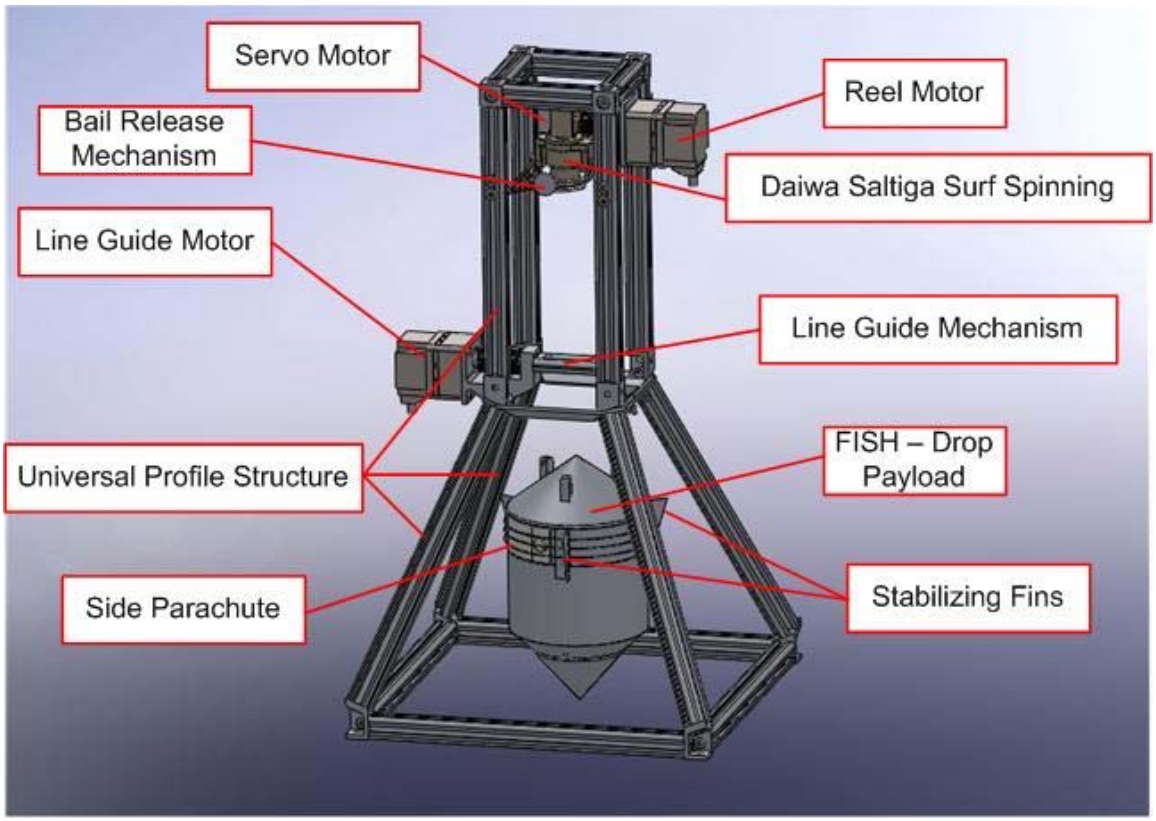



**Figure 3.8 Experiment Setup**

### 3.4.2 Interfaces

The interfaces of a project are a very important characteristic the quality and control of a design. Thus to ensure complete compatibility between subsystems an interface control document has been created with specific responsibilities and requirements. The document defines and controls the interfaces within, between subsystems and between the system and the gondola. The objective of this interface document is to achieve both physical and functional compatibility between all interrelated system elements (25). At the commencement of the project, subsystems defined their interfaces, authorities and responsibilities were assigned to one member on each side of the interface. This document thus identifies, defines and controls all intra- and inter- subsystem interfaces and external interfaces of the system.

The interfaces are divided into various types which include:

- Intra Subsystem Interfaces
  - Mechanical
  - Electrical
  - Software
- Inter Subsystem Interfaces
  - Mechanical – Electrical
  - Electrical – Software
- Subsystem to External Interfaces
  - Mechanical – Gondola
  - Electrical – Gondola
  - Software - Gondola

### 3.4.2.1 Mechanical interfaces

The mechanical interfaces are shown in Table 3.6. S1 refers to the member responsible for the first component, S2 to the second.

| ID # | Name (S1 to S2) | Function | S1 Responsibility | Design Info S1 to S2 | Parameter S1 to S2 | S2 Responsibility | Design Info S2 to S1 | Parameter S2 to S1 |
|---|---|---|---|---|---|---|---|---|
| **Mechanical** | | | | | | | | |
| Main Payload | | | | | | | | |
| Int.M.1 | Structure to Reel | Support the load for holding, reeling, and braking the FISH | Provide a sufficiently robust structure to support all loads | NA | NA | Provide a sufficiently robust reel to support all loads | Max. Loads; Attachment dimensions; | Attachment hole data |
| Int.M.2 | Structure to Line Guide | Support the load for holding, reeling, and braking the FISH | Provide a sufficiently robust structure to support all loads | Eq. Stiffness | TBD | Provide a sufficiently robust line guide to support all loads | Max. Loads; | TBD |
| Int.M.3 | Line to Reel | Provide last resort braking, i.e. High energy absorption | Provide a sufficiently robust line to support all the loads | MaxTension; Adhesive options; | TBD | Provide a sufficiently robust attachment solution to support the load and energy absorption | Rate of energy dissipation; | TBD |
| FISH | | | | | | | | |
| nt.M.4 | Line to FISH | Support the load of the FISH and transfer it through the line | Provide the line and a method of attachment to the structure | line diameter, method of attachment | 1mm dia. Splice-loop to loop the fishing line through the hole | Provide 3 holes on the FISH main structure for a line to be attached to | Hole attachment diameter, position of connection | 3mm dia. hole at end of the struts near tail |
| Int.M.5 | FISH to Parachute | Provide an attachment from the parachute to the Structure | Provide a structural hold to attach a parachute chord to it | Hole attachment diameter, position of connection | TBD | Provide a method of connection for the parachute cord to the structure | Parachord Diameter, method of attachment | TBD |

**Table 3.6 Mechanical Interface Table.**

### 3.4.2.2 Mechanical – Electrical Interfaces

| ID # | | Function | S1 Responsibility | Design Info S1 to S2 | S2 Responsibility | Design Info S2 to S1 |
|---|---|---|---|---|---|---|
| **Mechanical - Electrical** | | | | | | |
| Main Payload | | | | | | |
| Int.ME.1 | Engine to Reel | Transfer electromech. power to the reel-in operation | Couple the motor output to the reel's shaft; | Favorable output config.; Required torque and speed; | Select a suitable motor for the torque / speed req.; Design power electronics to control the motor; | Detailed motor data (size, mounting, weight, torque, speed, output); |
| Int.ME.2 | Engine to Bail | Provide a reliable actuation of the bail release mechanism | Design the interface to the bail, ensuring repeatable and robust operation; | Req. Output; Required power and speed; | Select a suitable motor/actuator for the required output; Design power electronics to control the motor/act.; | Detailed motor/actuator data (size, mounting, weight, power, speed, output); |
| Int.ME.3 | Engine to Brake | Adjust the strength of the reel's drum-brake | Couple the motor output to the reel's shaft; | Favorable output config.; Required torque and speed; | Select a suitable motor for the torque / speed req.; Design power electronics to control the motor; | Detailed motor data (size, mounting, weight, torque, speed, output); |
| Int.ME.4 | Structure to Engines | Secure the mounting of the motors to the structure | Mount the motors to the structure | Size and weight limitations; Geometric limitations and preferences; | Select motors which comply to the mechanical requirements; | Detailed mounting data, geometry, weight, thermal properties; |
| Int.ME.5 | Structure to Batteries | Secure the batteries to the structure | Mount the batteries to the structure | Size and weight limitations; Anticipated thermal conditions; | Select batteries which are sufficient and comply to the mechanical requirements | Detailed mounting data, weight, thermal requirements |

| | | | | | | |
|---|---|---|---|---|---|---|
| Int.ME.6 | Line Guide to Engine | Transfer electromech. power to the line guide | Design an input which is compatible to the output of the motor; | Favorable output config.; Required torque and speed; | Select a suitable motor for the torque / speed req.;<br>Design power electronics to control the motor; | Detailed motor data (size, mounting, weight, torque, speed, output); |
| Int.ME.7 | Structure to Electronics | Secure the electronics on the structure | Mount the electronics on the structure & provide a suitable thermal env. | Anticipated thermal conditions;<br>Anticipated impacts; | Design the electronics robustly, compactly, and thermally resistant; | Mounting information; Thermal req. |
| Int.ME.8 | Sensor Location | Provide mountings on the structure or other parts of the design for sensors | Mount all sensors in useful locations;<br>Provide suitable thermal environment | Anticipated thermal conditions;<br>Anticipated impacts; | Select sensor systems which comply to the environment; | Sensor geometries and thermal req. |
| FISH | | | | | | |
| Int.ME.11 | Structure to GPS | Provide the mounts for the GPS to withstand the forces experienced | Connecting the GPS to the structure, designing the mount | N/A | Providing the GPS and its parameters | Require size, mass, thermal and other constraining factors<br>Size: 70x47x16, M = 20g, Thermal: -20, 50, Require open sky view |
| Int.ME.12 | Structure to Circuit Boards | Provide mounts for the circuit board to withstand the forces experienced | Designing the mount and mounting the circuit board | The hole size and locations on the circuit board | Creating the PCB along with creating the mount locations (holes) in it | 3D size of circuit board, and position required<br>Size: Diameter, 70mm, height: 50mm, Position at CoG |
| Int.ME.13 | Structure to Antenna | Connect the antenna to the Structure | Designing the mount and mounting the antenna | N/A | Providing the Antenna and its parameters | Require size, mass, thermal, optimal location and other constraining factors |
| Int.ME.13 | Structure to Batteries | Provide Housing for the Batteries | Designing the mount and mounting the batteries | N/A | Providing the batteries and its parameters | Require size, mass, thermal, optimal location and other constraining factors |

**Table 3.7 Mechanical - Electrical Interfaces**

### 3.4.2.3 Electrical - Software Interfaces

| Electrical - Software | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Communication | | | | | | | | |
| Int.ES.1 | Payload to Ground-Station | Provide communication link between main payload and Ground-Station | Juxi | protocol/error correction, data rate | min. data rate 16 Kbit/s | Mikulas | Require protocol, possible error correction, data rate | Ethernet 10/100 via E-Link, max. data rate 2 Mbit/s (shared) |
| Int.ES.2 | FISH to payload | Provide communication link between FISH and main payload | Juxi | protocol/error correction | min. data rate 180 Kbit/s | Mikulas | Require protocol, possible error correction, data rate | ZigBee, max. data rate 250 Kbit/s |
| Microcontroller | | | | | | | | |
| Int.ES.3 | Reel Motor to DAC | Provide analogue value to control speed | Jan | analog signal | 0V-5V | Mikulas | require digital resolution | 0V-5V, 10 Bit |
| Int.ES.4 | Reel to ADC | Connect hall sensors to ADC port of microcontroller | Jan | analog signal | 0V-5V, 10 Bit | Mikulas | require analog values | 0V-5V |
| Int.ES.5 | Bail Servos to PWM | Provide PWM signal to control angle | Jan | PWM signal | N/A | Mikulas | connect servo to microcontroller PWM ports | N/A |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Int.ES.6 | Line Guide to DAC | Provide analogue value to control speed | Jan | analog signal | 0V-5V, 10 Bit | Mikulas | connect motor control lines to microcontroller | N/A |
| Int.ES.7 | Payload Accelerometer to ADC (3) | Convert analogue value to digital | Jan | ADC range + signal | 0V-5V, 16 Bit | Mikulas | connect IMU to microcontroller | N/A |
| Int.ES.8 | FISH Accel. Temp to SPI | Convert SPI to digital | Jan | SPI values | N/A | Mikulas | connect temperature sensor to microcontroller | N/A |
| Int.ES.9 | Payload Gyroscopes to ADC (3) | Convert analogue value to digital | Jan | ADC range + signal | 0V-5V, 16 Bit | Mikulas | connect IMU to microcontroller | N/A |
| Int.ES.10 | FISH Gyro Temp to SPI | Convert SPI to digital | Jan | SPI values | N/A | Mikulas | connect temperature sensor to microcontroller | N/A |
| Int.ES.11 | Payload Memory to Digital Port (8) | Process Secure Digital data format | Jan | digital signal | N/A | Mikulas | connect SD-Card socket to microcontroller | N/A |
| Int.ES.12 | FISH Memory to Digital Port (8) | Process Secure Digital data format | Jan | digital signal | N/A | Mikulas | connect SD-Card socket to microcontroller | N/A |
| Int.ES.13 | FISH GPS to UART | Process NMEA serial data | Jan | UART properties | N/A | Mikulas | connect GPS to UART ports of microcontroller | N/A |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Int.ES.14 | proximity sensor to Digital Port (3) | Provide position information of FISH | Jan | digital signal | N/A | Mikulas | connect proximity sensors to digital ports of microcontroller | N/A |
| Int.ES.15 | Heaters to Digital Port | Enable heater control | Jan | digital signal | N/A | Mikulas | connect heaters to digital ports of microcontroller | N/A |
| Control Algorithms | | | | | | | | |
| Int.ES.16 | Constant Speed slow reel algorithm | Control slow reel experiment | Jan | sensors/actuators | N/A | Mikulas | Provide sensor values | N/A |
| Int.ES.17 | Power On Reset | Provide safe power on sequence | Jan | sensors/actuators | N/A | Mikulas | Provide sensor values | N/A |
| Int.ES.18 | Bail Opening sequence | Provide reliable opening of bail | Jan | sensors/actuators | N/A | Mikulas | Provide sensor values | N/A |
| Int.ES.19 | Free fall sequence | Control free fall sequence | Jan | sensors/actuators | N/A | Mikulas | Provide sensor values | N/A |
| Int.ES.20 | Emergency line guide reel up | Control safe reel up in case of malfunction | Jan | sensors/actuators | N/A | Mikulas | Provide sensor values | N/A |
| Int.ES.21 | Brake failure detection | Provide algorithm to detect brake failure | Jan | sensors/actuators | N/A | Mikulas | Provide sensor values | N/A |
| Int.ES.22 | Bail failure detection | Provide algorithm to detect bail failure | Jan | sensors/actuators | N/A | Mikulas | Provide sensor values | N/A |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Int.ES.23 | Tether fail. Detect. (Parachute deploy) | Provide algorithm to detect tether failure | Jan | sensors/actuators | N/A | Mikulas | Provide sensor values | N/A |
| Int.ES.24 | Microcontroller watchdog | Control safe restart of microcontroller | Jan | sensors/actuators | N/A | Mikulas | provide power to microcontroller | N/A |
| Int.ES.25 | (FISH tangling damping) | Provide algorithm to dampen tangling during reel up | Jan | sensors/actuators | N/A | Mikulas | Provide sensor values | N/A |

**Table 3.8 Electrical - Software Interfaces**

### 3.4.2.4 Mechanical – Gondola Interfaces

| ID # | | Function | S1 Responsibility | Design Info S1 to S2 | S2 Responsibility | Design Info S2 to S1 | Parameter S2 to S1 | Design Info S2 to S1 |
|---|---|---|---|---|---|---|---|---|
| **Mechanical-Gondola** | | | | | | | | |
| Int.Gond.M.1 | Structure to Gondola | Provide sufficient strength and stiffness | Provide a sufficiently robust structure to support all loads | Terminal Loads; Require hole in floor (370-5mm x 370-5mm) | 10g vertical, ± 5g horizontal | Provide a sufficiently robust attach point to support all loads | Attachment dimensions; Eq. Stiffness | Rail distance, 370 mm & 375 mm, drill hole diameter, 5.25 |
| Int.Gond.M.2 | Structural – Gondola effects | Determine perturbations | Predict forces through the structure due to braking or jerks | Theoretical Model | Determine perturbations from Gondola | Investigate previous data | Tests, simple calculation | N/A |

**Table 3.9 Mechanical - Gondola Interfaces**

#### 3.4.2.5 Electrical – Gondola Interfaces

The electrical interface between the main payload and the e-link is to be Ethernet, physically connected via MIL-C-26482-MS3116F-12-10P. The schematics of the connection are in the BEXUS manual(26).

#### 3.4.2.6 Software – Gondola Interfaces

There is no direct interface between the software subsystem and the gondola

## 3.5 Mechanical design

The mechanical subsystem mechanically supports all of the reel.SMRT systems. It includes mechanical interfaces with the reel and motors, the MAIN Payload and the FISH and must satisfy all of the strength, stiffness, aerodynamic and stability requirements for the mission. The objective of the Mechanical Subsystem is:

Obj.M *To provide the mechanical capability for a free-fall action and reeling up and down of the FISH in a safe manner and also to provide a robust housing for the components that will enable them to survive flight conditions, whilst providing an easily accessible structure for assembly and testing.*

The external structure of the MAIN Payload and the FISH and the interfaces between them, carry the major loads and act as a barrier between the components and the external environment. The structure provides access to the components during testing and manufacture as well as the interface between sensors and the external environment. Additionally the structure must be built to withstand testing, storage and transportation. The internal structures support the circuitry and actuators. It also provides thermal and stress insulation from the extreme temperatures, pressures and conditions of the stratosphere and balloon flight. The mechanical design has been separated into 5 major components which include:

- MAIN Payload
- Reel
- Line Guide
- Line
- FISH

These structures have been designed and analysed separately with the interfaces between them presented in Section 3.4.2.1

### 3.5.1 MAIN Payload

The MAIN Payload was designed to support and hold all the components of the experiment. This included the reel system, the line guide system, safety guards, the bail release system, the batteries, the electronics, the insulation, and the FISH payload. In order to simplify the design process, off-the-shelf component use was maximised. Most of the structural elements of the MAIN Payload assembly rely on aluminium extruded profiles available at *Solectro* at reasonable costs (refer to Appendix M.3 for the complete product specifications). These products provide simple mounting and flexibility whilst keeping the weight to a minimum without significant loss of strength or stiffness. The analysis of the structure provided in (27) shows that these structures are strong and should provide enough strength to support the MAIN Payload's components. A detailed structural analysis will be performed to provide more confidence in the structural integrity, especially for the custom machined components of the assembly.

Figure 3.9 displays the structure of the MAIN Payload with primary components mounted upon it. The design concept was to use a four corner pyramidal structure to provide a stable base for the experimental elements of the payload. The FISH payload can then be enclosed within the pyramid structure. The pyramid will also act as a funnel to reduce the effect of disturbances to the FISH through compliant geometries, the detailed design of which are yet to be finalised.

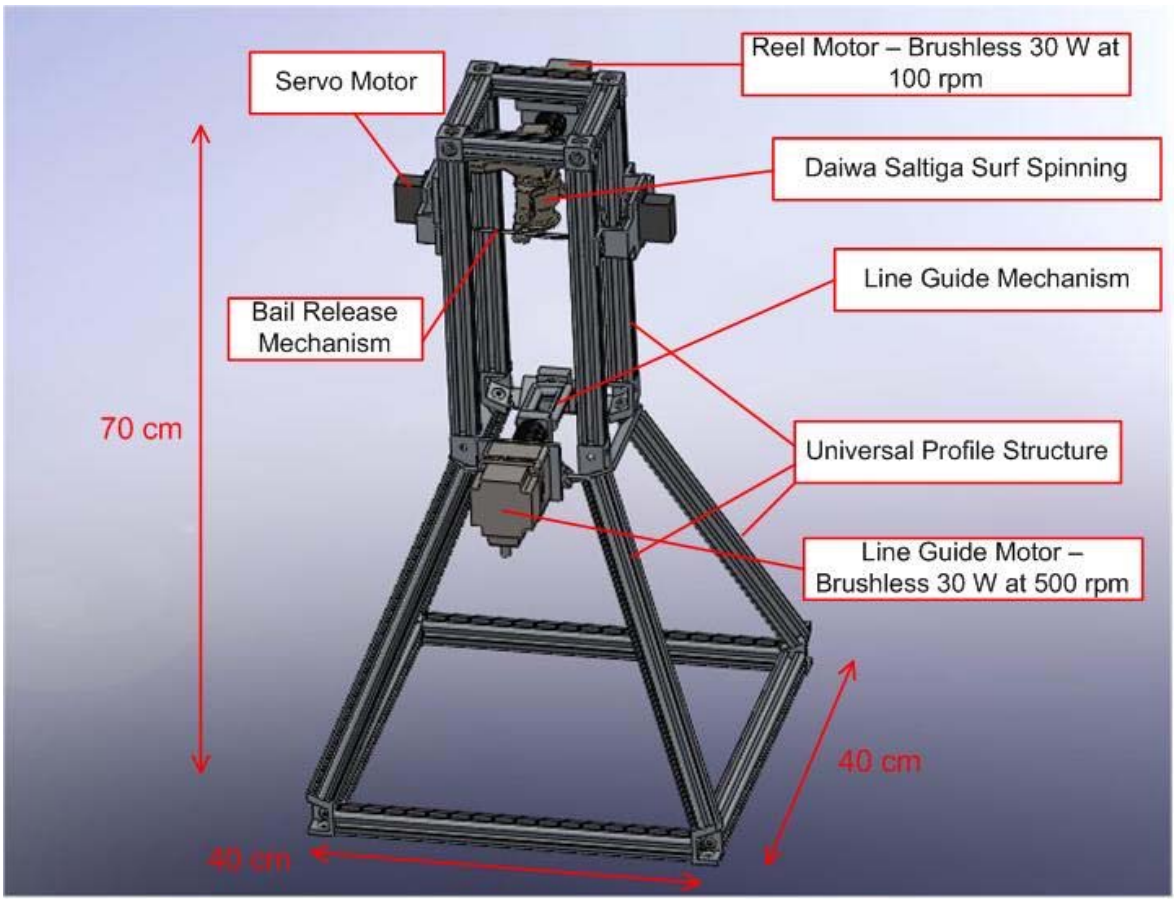

Servo Motor
Reel Motor – Brushless 30 W at 100 rpm
Daiwa Saltiga Surf Spinning
Line Guide Mechanism
Bail Release Mechanism
70 cm
Universal Profile Structure
Line Guide Motor – Brushless 30 W at 500 rpm
40 cm
40 cm

**Figure 3.9 MAIN Payload Structure and Components.**

From the top of the FISH and upwards, there are several distinct layers. First, a guard is provided as a safety mechanism in response to the Risk.M-M06. That is, in the case of a mechanical failure of the line guide system, the guard will prevent large broken-off pieces from falling from the gondola. Then, the line guide system was installed in response to Risk.M-M01 and Risk.M-M02, its function is to provide means of performing the basic operations of reeling the FISH up and performing the slow reeling down. The third layer is comprised of another guard, which prevents broken-off pieces from a failure of the reel mechanism (Risk.M-M01 and Risk.M-M02) from falling from the gondola. Finally, the reel system is fixed at the very top of the structure to provide maximum clearance for optimisation of operation.

The structure is predominantly composed of universal profiles. However, some custom parts are required for interfacing between the profile segments as well as for mounting the components of the experiment. Most custom machined parts will be constructed with aluminium alloy 6061 because of its availability at low cost and

its desirable properties such as its light weight and strength. This material is also easily machinable and weldable (but requires heat treatment). The facilities at the IRF and IRV should suffice to make all the necessary custom parts required in this design.

Not shown in Figure 3.9 are the electronic components and batteries. These are, however, simple to mount and should not pose any challenge as space is readily available on either sides of the structure. Also, the guards are not shown. The insulation structure is not yet finalised since it requires a more in-depth thermal analysis, see Section 3.6.1.

### 3.5.2 Reel System

The reel system consists of the reel itself, the reel motor, the bail release mechanism, as well as all the necessary mounting. The reel that is to be used in the reel.SMRT is a Daiwa Saltiga Surf 6000 Spinning reel. This is an off-the-shelf component whose main characteristics are summarised in Table 3.10. Refer to Appendix M.3 for further details.

| **Daiwa Saltiga Surf 6000** | |
|---|---|
| Brake pressure | 150 N |
| Mass | 530 g |
| Gear Ratio | 3.6 |
| Reel direction selection lever | Yes |

**Table 3.10 Daiwa Saltiga Surf 6000 Main Characteristics** (2)**.**

The choice of reel was motivated by multiple criteria, including:

- Reduced friction in the line when the FISH is in free-fall .
- High strength due to the magnitude of potential loading in emergency modes of operation.
- Strong braking mechanism to decelerate the FISH.
- Ability to control the ascent and descent of the FISH.
- Ability to work at high altitudes.

The reel chosen was the best compromise between all of these attributes, irrespective of price.

**Figure 3.10 Daiwa Saltiga Surf 6000 Reel** (2)

3.5.2.1 Friction Analysis

The concept behind the selection of a fishing reel for this experiment was motivated by the extreme low mechanical load from the reel after the release of the line. By opposition, a classical reel mechanism such as a winch or any other mechanism involving a pulley-type coupling to the line's dynamics will tend to absorb a large amount of energy through friction and kinetic energy build-up. Even a quasi-frictionless bearing would not help because the kinetic energy built up in the unwinding of the line is significant enough to drastically slow down the motion of a small weight under free-fall. The advantage of the fishing reel lies in the fact that the line is released completely from any coupling to the barrel. The working principle is based on a bail which winds the line around the barrel rather than the barrel turning to wind the line. The bail is then allowed to swivel and release its hold on the line completely and the line thus falls out of the barrel without inducing any kinetic energy build-up or any significant frictional forces.

The friction force between the line and the reel as the FISH is being dropped into free-fall is very difficult to estimate since it depends on many factors such as the speed of fall, the angle between the line and the reel, the actual winding on the barrel, the coefficient of friction between the line material and the edge of the barrel and between the line material and itself, as well as many other physical effects. One can start to analyse the friction on the line by considering two dominant effects: the friction between the line and the edge of the barrel; and the friction amongst the windings of the line as it gets unrolled.

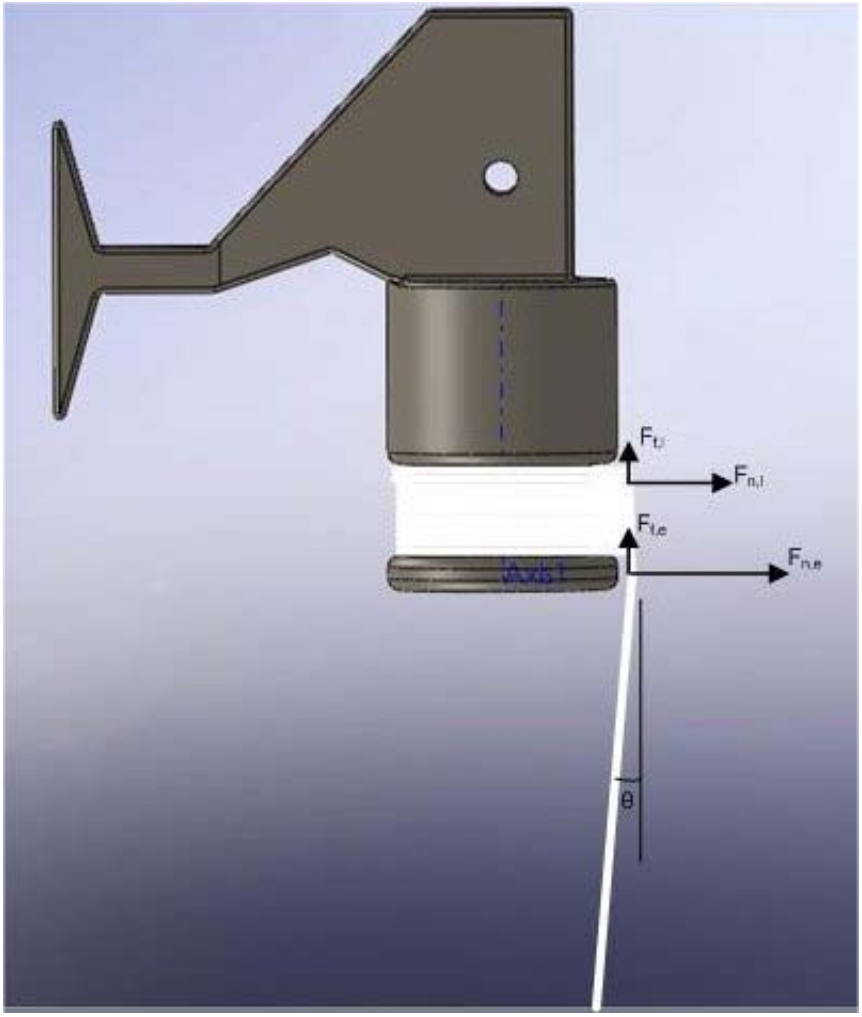



**Figure 3.11 Friction Forces on Line Release**

First, the friction between the line and the edge of the barrel is expected to be negligible. This comes as a result of considering the two factors that determine the friction force: the normal contact force and the coefficient of friction. The latter is expected to be very small due to the quality of the selected reel. It is one of the advertisement points of the manufacturer to be able to ensure very low resistance on a line when casting. Hence, the coefficient of friction can easily be estimated below 0.05 since the selected line is also of advertised as smooth and frictionless. The main factor to justify neglecting the friction between the line and the edge of the barrel is the small scale of the normal force. The pulling force coming from the FISH's dropping acceleration is transferred to a normal component to the edge of the barrel through the angle θ, see Figure 3.11. The angle is made small due to the small size of the barrel in comparison to the distance to the bottlenecks created by the line guide and the guards. The residual normal force is consequently very small and the induced Coulombic friction negligible. However,

the friction force does remain linear dependant on the amount of line which is trailing behind the FISH, it yet remains to determine to what extent it can remain negligible. Testing or further simulations will need to be performed to determine the angle of the line which is strongly dependant on the wave propagation through the tether.

Second, the friction force between the falling line and the windings on the barrel is also negligible through similar arguments as the aforementioned friction force. Again, due to the assumed smoothness of the line, the coefficient of dry friction of the line material with itself is assumed to be very small. Then, the scale of the normal force on the line is again very small because the path of the line is straightened by the edge of the barrel. Another favourable physical effect is the tensioning of the wound line. As the line is tensioned on the barrel, through the winding of the line while in tension, when it is released, the elasticity of the line will tend to straighten it and it will naturally expand away from the barrel, although the extent of the contribution of this effect is still to be determined through simulation and analysis. Furthermore, this friction force is highly stochastic because of the unpredictable details of the line winding on the barrel. Depending on the order at which the line is rolled on the barrel, the impedance of the one turns over the release of the other turns is highly unpredictable. In summary, it was determined that this reel system is the best choice for minimizing the resistance to the free-fall of the FISH, not to mention its practical advantages.

Brake Analysis

The brake of the system has been analysed to one of the more important safety components of the system. Thus a larger level of study has gone into this device. In the previous design the reel.SMRT was meant to have a variable brake system with a motor interfacing with the brake and hence being able to control it. Unfortunately due to reel constraints this idea was substituted for a non-variable brake which is preset before launch. This has many advantages and disadvantages, firstly with a variable brake the user is able to control it hence can increase the force is the brake is not working. This is a more adaptive method to unforeseen environmental hazards. The disadvantage with the variable brake is that increases the complexity of the system and also it is reliant on more systems to work for the brake to function which is a safety risk in itself. Thus it has been decided that a non variable brake is best of the system.

The reel brake has a maximum force 150 N which allows for a wide range of brake strength alternatives. In Figure 3.12 it is shown the stopping distances and time for different brake strength along with the g's that are experienced by the FISH in Table 3.11.

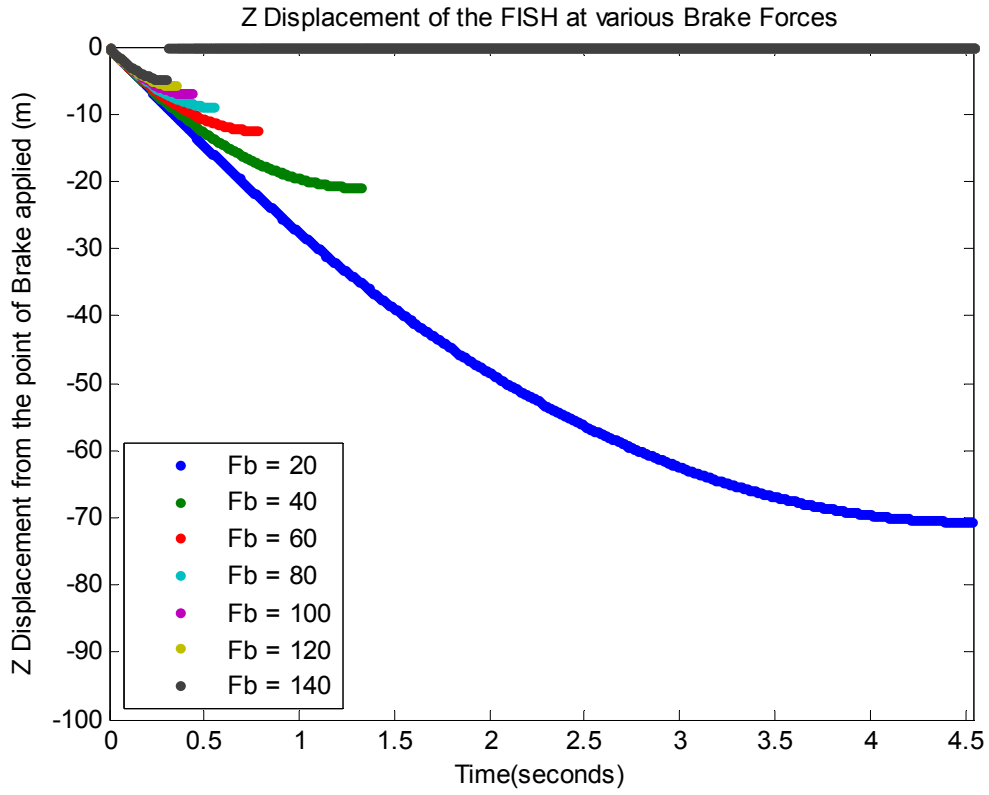



**Figure 3.12: The FISH's displacement for different Brake Forces**

| Displacement and G's Experience by FISH for various Brake Forces | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Brake Force (N)** | **20N** | **40N** | **60N** | **80N** | **100N** | **120N** | **140N** |
| **G's** | 0.7 | 2.4 | 4.1 | 5.8 | 7.5 | 9.2 | 10.9 |
| **Max displacement when braking (m)** | 70.5 | 20.9 | 12.4 | 8.9 | 7.0 | 5.8 | 5.0 |

**Table 3.11: Characteristics of the FISH at Various Brake Forces**

When looking at the G's experienced by the when the brake is applied one can see that the larger the brake force the large the G's that are experienced. For the near maximum braking force applied the G's experience are at approximately 12 which is still well inside the structural limits of the FISH. Thus the braking distance and reliability of the brake are the most important factors for deciding on which brake strength to pre set the reel too. For the reliability of the brake it is never a

good practice to the strength of the brake to near the limits, thus the maximum force will be approximately 100N. The absolute minimum force is 10N otherwise the FISH will never slow down and hence it is recommended to be well inside this parameter. Hence the Braking force has been chosen to be between 60 – 90 N because it is well inside both limits of the G's and min brake force as well as the amount of line that is used for braking is relativity short.

To make sure this system is safe and the brake will work every time the system will be tested under a various mission environmental conditions. How these conditions will affect the brake will be determined in the tests and the Brake force will be set accordingly. In conclusion a non variable braking system will be used to reduce the velocity of the FISH because it increased complexity of the system thus increases the relative safety of the braking system. This brake will be pre set before mission launch to 60-90 N.

The reel motor that was selected was a brushless DC motor with 24 V input and rated at 30 W output at a nominal speeds of 6.7 to 167 rpm with a rated torque of 1.6 Nm under continuous operation (please see Appendix M.3 for more details on the model AXH230KC-15). This was determined to be sufficient, with a safety factor higher than two, for all operations required by the reel system, especially reeling the FISH back from at most 100 m down within 2 minutes. The manufacturer of the product is an American company named Oriental Motor USA Corporation; they provide industrial grade motors, compliant to many industrial standards, which are available at reasonable prices. The choice of brushless motors was based on reducing EMI effects on the MAIN Payload and the gondola, as well as reliability issues with brushed motors that would not respond well to the stratospheric environment, according to the contacted manufacturers. The main remaining issue with the selected motor is the operating temperature (-10°C to 40°C): it remains to be determined whether the specifications given by the manufacturer are based on performance or critical failure or neither. This could possibly lead to a reselection of the motor.

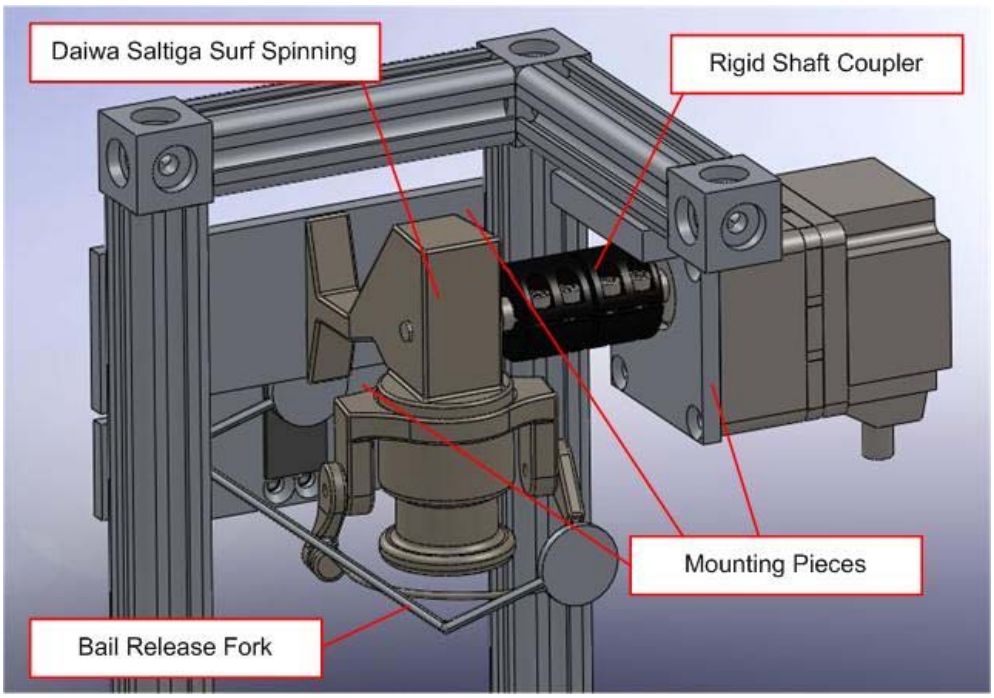



**Figure 3.13 Reel System**

The bail release mechanism was designed as a fork that shall push the bail from its closed position to the open position, effectively releasing the line and the FISH to free-fall. The design is aimed at simplicity, reliability, and redundancy. To power the mechanism, two servo-motors (*Hitec* HS645MG) are used. These drives have the advantage of providing an independent position control that simplifies the implementation of the electronics. Two drives are provided for redundancy in this critical element of the design. The operation sequence starts from the bail lying at a specific position, detectable through contact sensors, and then, it is released by turning the servo-motors at least 90 degrees such that the fork will make contact with the bail and push it to the open position via a rotary motion.

The mounting elements of this design are very straight forward. The elements of the reel system are mounted on the universal profile structure which surrounds the area where the reel is placed. Mainly built of custom components in aluminium, the mounting pieces are easily interfaced to the profiles using M6 screws and matching sliding nuts, also available at *Solectro*. The sliding nuts also provide the flexibility to adjust the design in the event of modifications to the reel's geometry or motor selection after this preliminary design phase.

### 3.5.3 Line Guide System

The line guide system was implemented as a redundant mechanism in the event of any failure in the reel system; the line guide system is a safety feature. The functionalities of the line guide are limited to reeling the FISH up and down, that is, no free-fall is possible through control of the line guide. The line guide also serves the purpose of a redundant braking system (Risk.M-M03, Risk.M-M04, and Risk.M-M07). The design of the line guide is very simple: It consists of a motor, very similar to the reel motor, but with a smaller gear-ratio, and a “cage” structure which can be turned and the line winded around it. In order to stop the FISH in free-fall, the line guide is turned, and consequently, impeding the fall of the FISH to an eventual complete stop. To reel back the line, the line guide is simply turned all the way until the FISH is back inside the MAIN Payload; an operation which may be performed virtually at the same speed as the reel system. Depending on the conditions after the recovery from either aforementioned failures the mission can continue, but is limited to the slow lowering of the FISH below the gondola before normal operations may recommence.

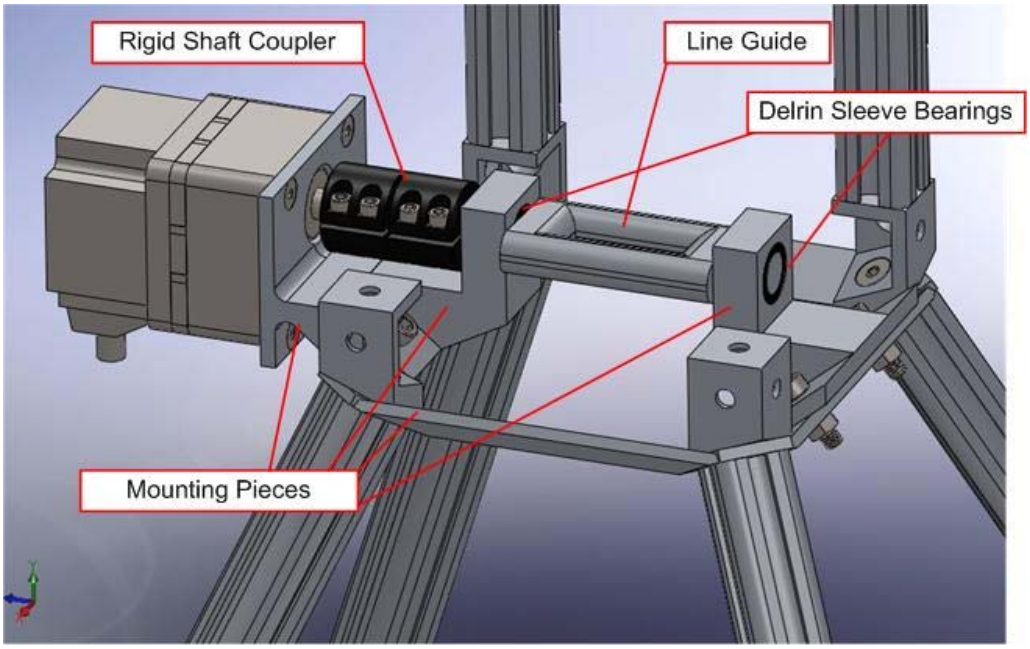



**Figure 3.14 Line guide System**

As of the specifics, the motor selected to power the line guide is the same as for the reel system with the difference of a reduced gear-ratio, (see Appendix M3 for model BLH230KC-5), to take into account the absence of the gear-ratio of 3.6:1 in the reel itself. The bearings used to support the line guide are Delrin sleeve bearings which support high loads and high rotational speeds, operate over a

large temperature range, and avoid the use of any lubricant. The custom pieces will again be machined in aluminium.

### 3.5.4 The Line

The *Platypus* Super-Braid (3) is the line chosen to fulfil the needs of the reel.SMRT. It is composed of Ultra-High Molecular Weight Polyethylene(UHMWPE) from a company called Dyneema (3). It has a 200lb (890 N) maximum load and is able to with stand temperatures at to below -150$^{o}$ C with minimal compromising effects on the strength of the line (4). It is also lightweight with a density of 0.97 g/cm$^3$ (4).which reduces the effects of the line momentum on the FISH when in free-fall. It is easily bendable, it has a very small line memory and resistant to UV. (4)

To attach the line to the strut the line is fed through the rounded holes that are present in the strut (the struts are explained further in 3.5.5). One the line is placed through the hole the next issue it how to connent the line back on itself. When a knot is tied in a fishing line it creates faults and will reduce the strength of the line to as much as 50% (24) To maintain 100% of the line strength a method called splicing is used. This is a form of connecting is basically interweave the braided line back on itself. The individual strains in the line are weaved amount each other at the point of contact thus creating no potential faults. This method takes time hence why it is not commonally used in FISH but it is the strongest form of connecting two braided line together. This method of connection will allow for a better connection to the FISH and thus significantly reduces the chances of the line breaking.

Another device connected to the Line is a swivel to reduce any major spinning motions created by the reel being transferred to the FISH. The actual swivel has not been chosen presently and a further analysis on best swivel for the job needs to be completed. Further tests of the affectiveness will be completed in the testing phase.

### 3.5.5 FISH

The FISH essentially a sensor package design to protect the electronics from the mission hazards whilst reducing the effects of the atmosphere on the results, through a minimum drag profile and a thorough safety system. Thus, the FISH does not provide an internal capsule for additional scientific payloads as would be implemented in any final product. A design of the FISH is shown in Figure 3.15.

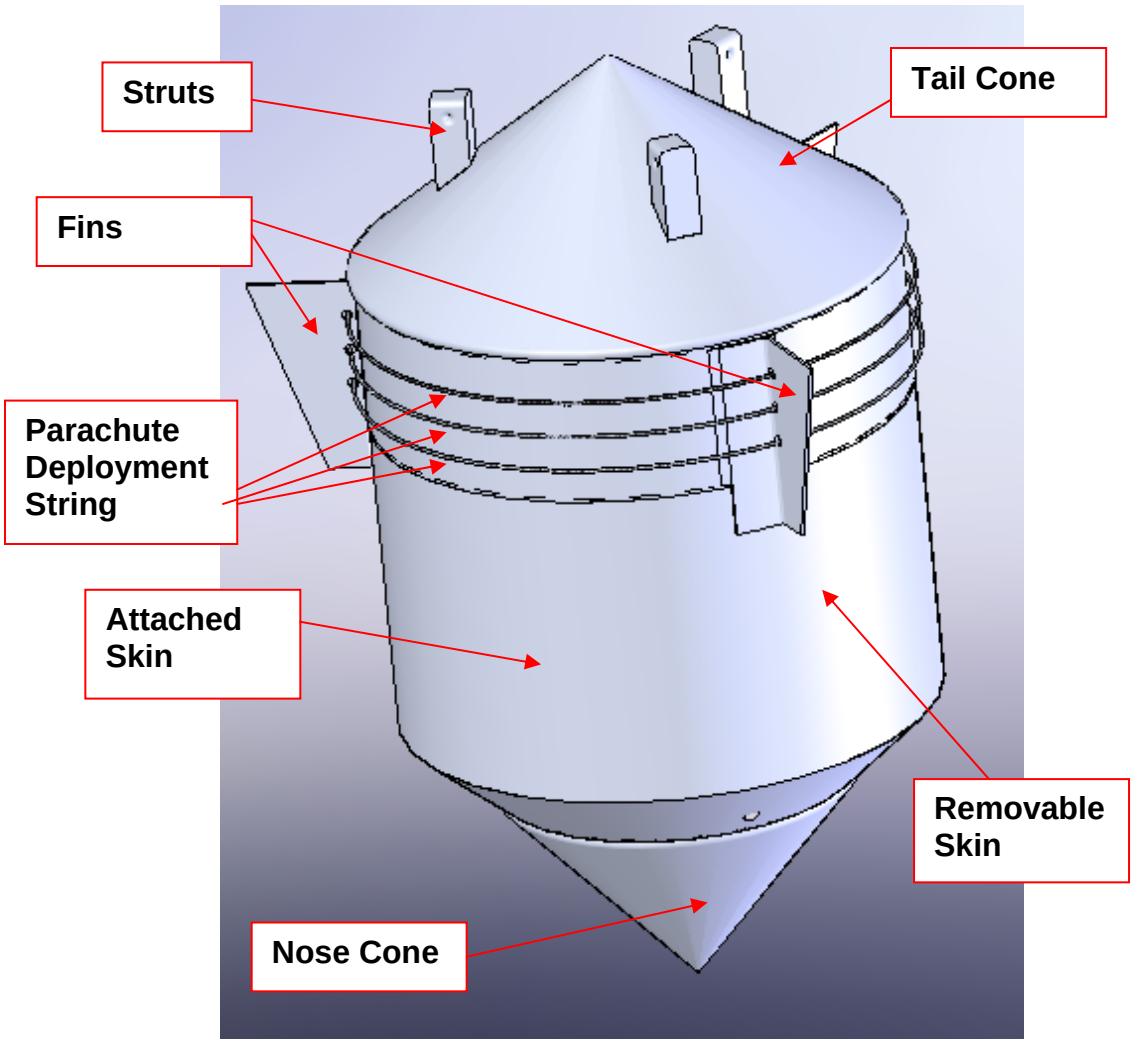



**Figure 3.15 The FISH Design.**

The FISH comprises of multiple components that are joined together to give the optimal layout while still maintaining its structural integrity. This structure comprises of a cylinder body with a tail and a noise cone attached. The direction the capsule's nose is point is towards the earth (down the page) with the tail facing the gondola. The three long metallic objects are the struts which are connected line at the holes near the tail. Below this point is the tail cone where the ZigBee and the antenna are located. Below this is the Tail plate with the parachute housed underneath. The same structural components exist at the nose except that the struts stop and are attached at the nose plate. In between the tail and nose plate are a variety of electrical components including the parachute, GPS and electrical circuitry (order from tail to nose).

A general summary of the FISH is a length of 270 mm and a diameter of 150mm (Appendix A4). The mass is approximately 1200g (Appendix A2 ).

As one can see the FISH is a cylinder with a nose and tail cone attached. These cones are designed to reduce the effects of atmospheric drag (Req.O.M.1) on the capsule without making the design too complex. These shape should produce a coefficient of approximately $C_d$ = 0.8 (5) and a higher accurate value shall be obtained through wind tunnel tests.

Inside the FISH there are three main struts that are connected to the line. These are 200 mm long Aluminium 6061 struts with a width and breadth of 10mm. The struts are designed to withstand the maximum force of the FISH under its critical loads of 10g (100N), as must be withstood according to the BEXUS User Manual (6). These struts are able to endure these forces with a factor of Safety (FS) of 30 (Appendix M2) thus making the main structural component very strong and dependable (Req.F.M.1).

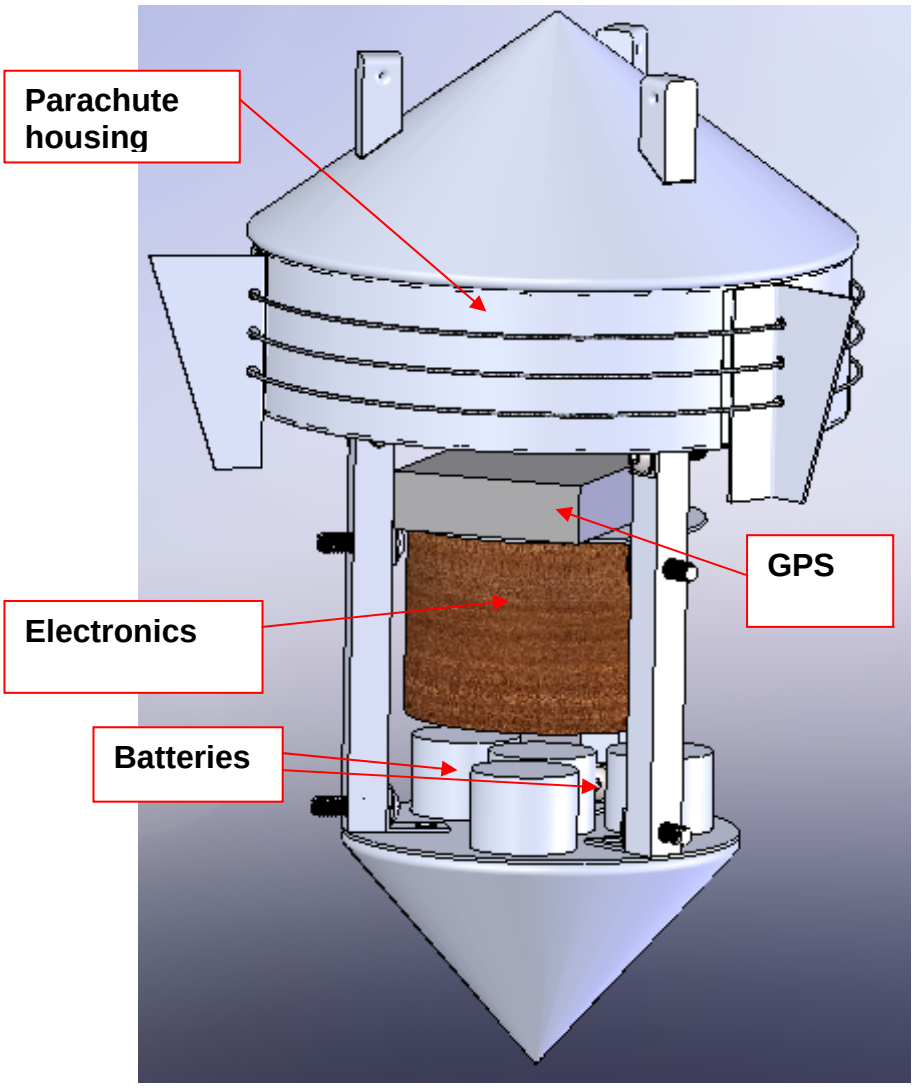



**Figure 3.16: The FISH internal Design**

The next design consideration for the FISH was the layout. This layout has a few restrictions predominantly incurred as a result of the size and constraints of the each component and the aerodynamic stability of the capsule. In Table 3.12, specific constrains for each component are stated.

| Component | Constraints |
|---|---|
| Electronics | The accelerometers and Gyroscopes must be located close to the centre of gravity of the FISH |
| Parachute | Must be located near the rear of the |

| | |
|---|---|
| | FISH |
| GPS | Must be able to receive signals at the correct frequency (C.M.2) |

**Table 3.12 Constraints on components of the FISH.**

For the FISH to be stable during the free-fall phase, the aerodynamic centre is required to be at a higher altitude than the centre of gravity. For this to be achieved all the high mass components of the FISH need to be situated near the nose. Thus for the FISH design the batteries, electronics and GPS are located as close to the nose as possible to lower the centre gravity to the position of approximately 150mm (from the noise). Also stabilisation fins are placed near the rear of the FISH to move the Aerodynamic Centre (AC) closer to the tail. The AC is predicted to be located at 170mm with a 10% accuracy. Thus the static margin is 0.06 thus allowing for a stable design to provide more accurate measurements with minimum interference from the aerodynamic effects (Req.O.M.3).

To hold these components in place various tiered level plates have been inserted which are connected to the struts via corner brackets. The tier method of stacking of the component has been chosen due to the flexibility of moving the components up and down the struts if the CoG needs to be adjusts as well as the maintenance of the FISH symmetry for horizontal CoG placement. The disadvantage with this layout is that the accessibility of the components have been reduced, along with a bending moment being place through the equipment. To negate the bending moments, plates have been place below each component which in turn will reduce the forces the components will experience.

The outer layer of the FISH is a combination of aluminium skin and insulation. The skin is divided into two parts: the parachute skin and the electrical skin. The parachute skin is permanently fastened to the structure because once the parachute is inserted into the structure there is no need to access it. The electrical skin (along with the insulation) is able to be removed by simply unscrewing eight screws attaching the skin to the main structure. This allows for easy access to all electrical components during insertion and testing, thus not constraining the mechanical construction to the electrical subsystem timetable. It also allows for faster testing, which in turn facilitates the improvement of the quality of the software and electrical designs.

#### 3.5.5.1 Safety Parachute

After the risk analysis it was assessed that a parachute was needed on the FISH for the proper implementation of a safety system (M-M08, M-M09) and to satisfy

requirement Req.O.3. The parachute that was chosen was a 'Flat Circular Canopy' with a diameter of 1.2-1.5 m produced the company *Airsafe* (7). The parachute will have 8 lines of the same length and will only have one attachment to the Capsule. It shall be deployed from the side of the capsule due to the potential hazard of the Fishing line being attached above the FISH and thus interfering with the opening of the chute. The storage size is approximately 0.1- 0.15 L and the parachute chord only needs one major attachment, which shall be mounted to the struts. When the deployment occurs the maximum g's produced will be approximately 4g, which is inside the force capacity of the FISH, thus the fulfilling Req.T.M.1. The specifics of the parachute are still under analysis and review due to the present consultation with the *Airsafe* company (7).

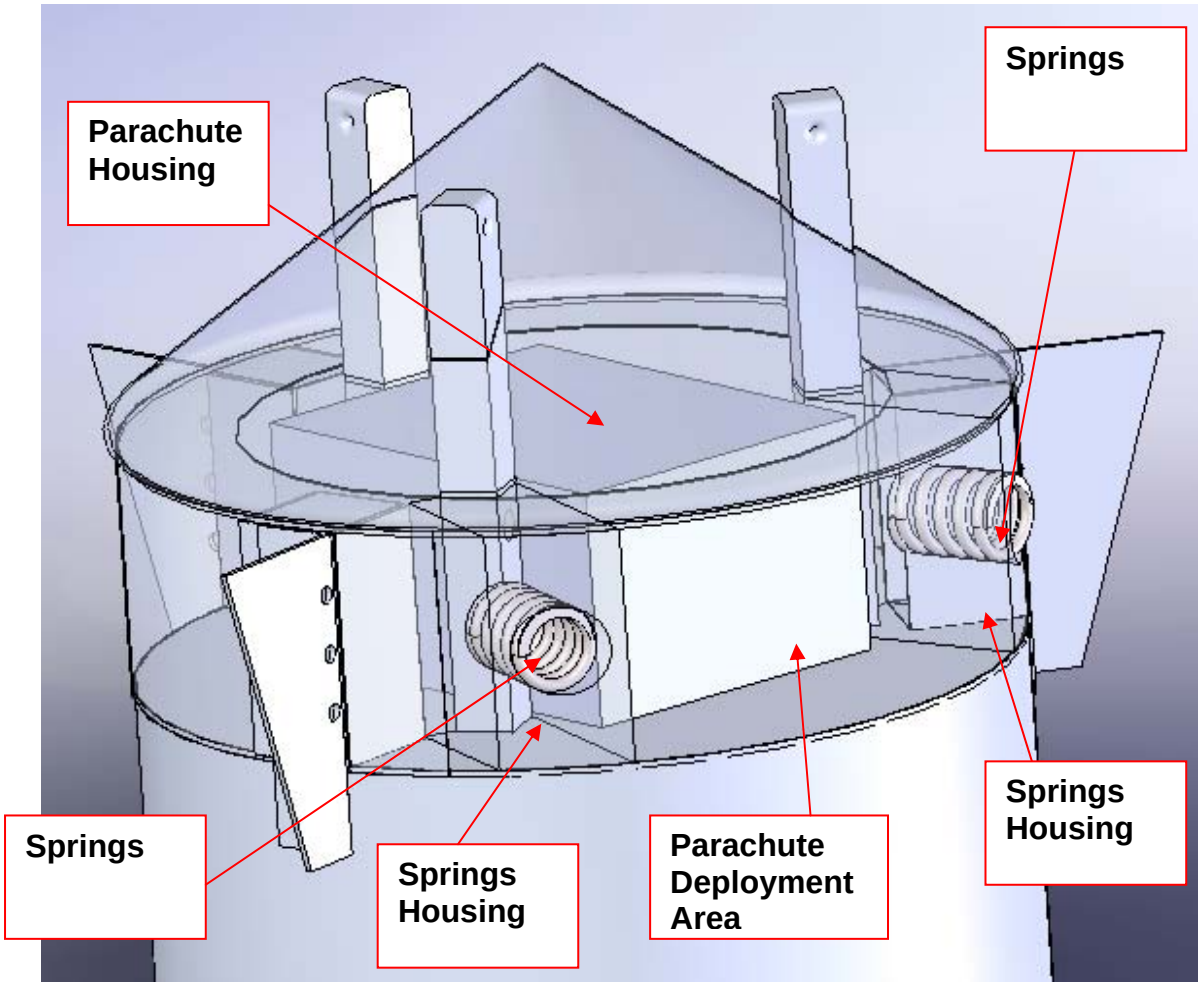



**Figure 3.17 CAD drawing of Parachute deployment Mechanism.**

The deployment mechanism of the parachute requires two events to occur. Firstly, the removal of the lid from the structure to create a gap in the FISH for the

parachute to move through, and secondly, the actual deployment of the parachute from storage. To address the first issue, four sets of springs are attached to the structure and the parachute lid is placed on top. The lid is held down via 3 loops of Fishing line (depicted in Figure 3.17) which is tied around the complete structure and the lid. Heating elements are also wrapped around specific point on the line in preparation of the release mechanism. When the parachute needs to be deployed the lid is remove merely by sending a current to the heating elements which burns the wire and in turn the lid is jettisoned allowing for the ejection of the parachute. This is a simple and reliable design allowing for a parachute deployment thus fulfilling the requirement of Req.T.M.3.

## 3.6 Thermal design

The extreme cold of the stratosphere necessitates thermal insulation in order for the electrical components to remain within operational limits. Thermal control in this project incorporates both passive and active elements. Thermal control is critical to satisfying requirement Req.O.2. As such, a thermal analysis was conducted to determine both how to optimise the thermal design and the operational lifetime of the reel.SMRT system.

The reel.SMRT system is designed for flight at an altitude of between 25 and 35km. The temperature differs with height but the lowest temperature the balloon is likely to encounter is 210K. The ground temperature will be between 250K and 270K.

The MAIN Payload and FISH each present unique thermal design challenges. The MAIN Payload must be of sufficient temperature for the electronics to function, whilst not overheating the motors in this low-pressure low-convection environment. Conversely, the FISH must insulate the internal components such that the sensors and the electronics are stable and within operation ranges, whilst constrained in mass and volume.

In this section, the preliminary thermal designs to address these challenges to the MAIN Payload and the FISH are presented.

### 3.6.1 MAIN Payload

The MAIN Payload poses many challenges in the thermal aspects of the design. It is now premature to be able to fully analyse the thermal processes involved in the MAIN Payload, and hence, the present section will outline some of the challenges ahead and propose solutions. To start the analysis, the heat sources and sinks have to be identified. The most obvious heat sources are the motors; these include two brushless DC motors and two servo-motors. It is first noted that the two servo-motors are only operating for a very short period of time and therefore, their heat generation may be essentially neglected. The DC motors, however, will reject a

large amount of heat during their operations which can extend up to 0.5 duty cycle over five minutes or even up to an almost full duty cycle during the slow reeling down of the FISH payload. The electro-mechanical efficiency of motors can be estimated with good confidence to 50 %, including the gear-head losses. Overall, for power outputs of 30 W for each motor, the estimated heat rejection from the losses in the motors is of about 30 W per motor. Note that under no circumstances do the motors operate at the same time. This results in a total heat rejection of 30 W for all electric machinery, possibly up to a full duty cycle.

The second main heat source is the Li-Ion battery pack, which will typically have an efficiency of no less than 90 % (7). For this application, the operating power, under normal conditions, can be estimated to less than 80 W. This leads to a heat production from the batteries of at most 8 W. Finally, with the addition of the electronics components and other frictional losses, the overall heat production over normal operation should be no more than 45 W.

The heat rejection would be through the radiation and conduction from the inside components to the inside of the insulation casing and then through radiation into the atmosphere. It is very difficult at this preliminary design stage to estimate the heat loss, and hence, the thermal strategy shall be formulated with the assumption that the heat rejection can be brought to a minimum with proper insulation.

Table 3.13 presents the thermal requirements for the various components in the MAIN Payload. It may be observed that the temperature ranges are quite permissive. Some electronics are preferred to be kept at a constant temperature above the freezing point, especially for the present selected brushless motor controllers. All other mechanical components are permitted to be kept in a temperature range of -20 °C to 50 °C.

| Selected Components | Temperature (°C) | | Heat Generation (W) | Comments |
|---|---|---|---|---|
| | Min | Max | | |
| **MAIN** | | | | |
| Reel Motor | -10 | 40 | 30 | Around 0.5 Duty cycle over 5 min<br>Up to full duty cycle<br>Does not operate with Line Guide Motor<br>Investigate magnetic losses and heat radiation properties of the permanent magnet rotor |
| Line Guide Motor | 0 | 50 | 30 | Around 0.5 Duty cycle over 5 min<br>Up to full duty cycle<br>Does not operate with Reel Motor<br>Investigate magnetic losses and heat radiation properties of the permanent magnet rotor |
| Servo Motor | -20 | 60 | ~ 20 | Negligible operating period |
| Batteries | -20 | 85 | 8 | Possible destructive test required |
| Electronics - PCB 1 | -40 | 85 | < 1 | Continuous operation |
| Electronics - PCB 2 | -40 | 85 | < 1 | Continuous operation |
| Sleeve Bearing | -30 | 85 | < 2 | Verify Thermal Compatibility |
| Reel | N/A | N/A | ~ 5 | Testing Required ASAP |

**Table 3.13 Thermal Data for the MAIN Payload.**

The thermal strategy formulated is based on minimizing the power consumption of any required heating elements. In order to achieve this goal, the insulation will be made as good as possible such that no heat flows out of the MAIN Payload. During the pre-experiment phase, the temperature of mechanical components will be kept to no less than -20 °C by means of heating elements. Then, during the experiment phase, the heating elements will be turned off and the heat generated from the aforementioned heat sources will slowly heat the mechanical components of the MAIN Payload through conduction. The heat capacity of all components, based on the assumption of negligible heat flux to the surrounding environment, shall be sufficient to keep the overall temperature of the mechanical components below 50 °C during the whole experiment. The following rough calculation gives the time required to heat the components from -20 °C to 50 °C.

$$C_{th} > c_{al} \cdot m_{al} + c_{st} \cdot m_{st} \quad (1)$$

$$C_{th} > 0.896 \frac{J}{g℃} \cdot 3270\ g + 0.46 \frac{J}{g℃} \cdot 4400 g = 4954 \frac{J}{℃} \quad (2)$$

$$\dot{Q}_{gen} \cdot \Delta t = C_{th} \cdot \Delta T > 4954 \frac{J}{℃} \cdot (50\ ℃ + 20\ ℃) \quad (3)$$

$$\Delta t > \frac{346780\ J}{45\ W} = 7706\ s = 128\ min = 2.14\ hrs \quad (4)$$

The above equations show that it should be possible to operate the experiment for the required time without overheating the components of the MAIN Payload, even in the absence of any heat rejection to the outside environment. In practice, the conduction of the heat throughout the mechanical components will not be instantaneous, although aluminium offers great thermal conductivity, and hence, the temperature will not be uniform. This problem will be counteracted by measures to facilitate conduction around the heat source and improving thermal interfaces between components. The heat loss, although reduced to a minimum, will favour the extension of the time before overheating the mechanical components of the MAIN Payload. Additionally, temperature sensors can be installed inside the MAIN Payload to assess the thermal balance and ensure that the heat sources can be shutdown in time, e.g. between 50 °C and 60 °C.

Clearly, further thermal analysis is required to confirm the feasibility of the above strategy. Research shall be conducted to find proper materials for promoting conduction through the internal components and insulating the payload from the external environment.

### 3.6.2 FISH Payload

The thermal requirements of the FISH are dictated via the operating temperatures of the electrical components shown in Figure. The optimal temperature for the complete FISH is 20$^{o}$C but it needs to be analyses whether this is viable.

| **FISH ELECTRONICS** | | | | |
|---|---|---|---|---|
| Accelerometer Colibrys | -55 | 125 | nil | |
| ADR445 B grade | -40 | 125 | nil | optimal Temp 20C |
| TMP275 | -40 | 125 | nil | |
| LIS3L02AQ3 | -40 | 85 | nil | |
| ADC1253 | -40 | 85 | nil | |
| ZIgbee | -40 | 80 | nil | |
| Phoenix GPS Receiver | -20 | 55 | nil | |
| Antenna | | | nil | |
| Batteries | -60 | 80 | | |

**Table 3.14: Thermal parameters for the FISH components**

The thermal analysis that was completed via assuming that the main heat loss was due to radiation and the majority of heat stored was in the insulation. There is also the potential for a possible heat source located inside the FISH. A Few other

assumptions were made including the container is a cylinder and the material was Styrofoam along with that all radiation is done through the aluminium skin. The results are shown in Figure 3.18: Temperature inside of FISH for various thicknesses of insulation over a 5 hour period (potential mission flight time) with the outside temperature of -70 degrees and the inside temperature starting at -20 (launch pad temperature minimum). The calculations are shown in Appendix M1.

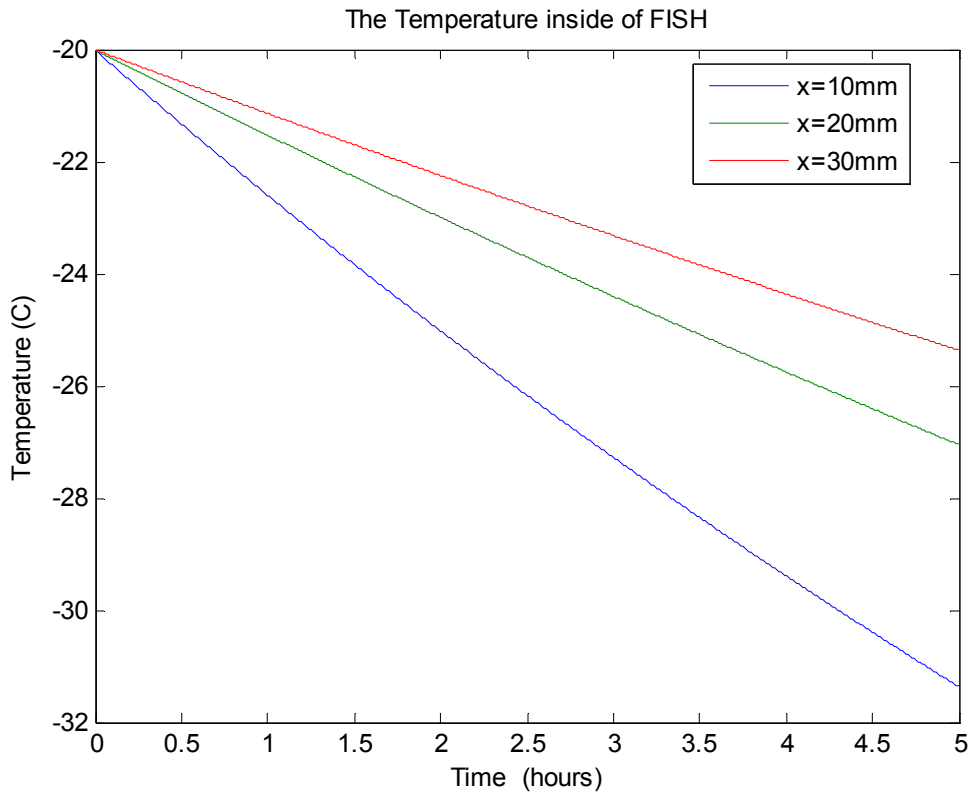



**Figure 3.18: Temperature inside of FISH for various thicknesses of insulation**

The temperature values purely due to radiation which is very dependent on the surface area of the FISH and the emissivity of the material. One can see that if there is no active heating inside the FISH then the temperature will reduce and if a long enough time passes it will reach -70$^{o}$C. Thus heating is required from the FISH to maintain an internal temperature for the optimal temperature of the components.

The calculation s involved to find the energy needed to raise the internal temperature is located in Appendix M1. It was found that a heating element of approximately 2 W is needed to maintain a stable 20$^{o}$C environment.

In conclusion, the internal temperature of the FISH is unable to be stabilised to within critical temperature limits by a passive heating case during the most extreme conditions. Thus a 2 W heater will be placed inside the FISH, in addition to the insulation, to ensure the thermal conditions enable all components to stay within their operational temperature limits.

## 3.7 Power System

The MAIN Payload is to use 4 packs of 11.2V 2200mAh Power Polymer Li-Ion Pack. These are to be connected serial/parallel to achieve 22.2V of nominal voltage and a nominal capacity of 4400mAh. This capacity, however, is assumed to be available at 75% due to the low temperature and as a safety margin. Since these batteries are rechargeable there is no need to use an external power source. The specific type of batteries for MAIN Payload is:

*AA Portable Power Corp - High Power Polymer Li-Ion Pack - 11.1v 2200mAh (24.42Wh, 40A rated)*

These battery packs were selected because they are extremely light and provide high current capabilities. This current will also be limited by PCM to match the stall currents of the motors.

### 3.7.1 Power Budget for MAIN Payload

The most significant energy consumption comes from the motors and mainly the reel and line guide motors. The reel motor is to be used for 10 drops each lasting 120s based on specification from mechanical subsystem. The motor is to consume 60W rated at 24V. One motor which corresponds to the three parameters is RE30 (Maxon, re-max). This motor is 60W rated at 24V. The continuous current for this motor is 3.44A . If the motor is to be operated for 20 minute, it will consume 1.14Ah. The battery pack has to provide this energy. The battery pack in the low temperature will have reduced capacity (75%). If only two 11.2, 2220mAh packs are used the total energy is to be 1.65Ah. In order to unsure correct operation during whole mission, four battery packs are to be used in the main payload. The total energy will be 2.2*2*0.75=3.3Ah, which is a three times more that the power required for the motor.

The electronics themselves will not draw more than 500mA in steady state (microcontroller, IMU,GPS, and Zigbee). Moreover, since there is to be switching power supply, the consumption is to be effectively decreased by the factor of 4 (24/5).

## 3.8 Software Design

The reel.SMRT experiment is very complex with regards to control and data storage process. In order to control the entire experiment and to be able to store the sensor data at the same time while having enough processing power remaining to check the whole setup for malfunctions, a very thoroughly designed software architecture is necessary.

The microcontrollers (NXP lpc2368) were selected so that they can provide the necessary processing power during all times of the flight. This microcontroller runs at 70 MHz and provides diverse inputs (analog-to-digital converter, UART, SPI, I²C, secure digital interface) to easily connect all sensors without the need of additional external converters.

The first microcontroller is located on the FISH, the second one on the main payload. In Figure 3.19 you can see the connection of the sensors and the communication links between the FISH and the main payload.

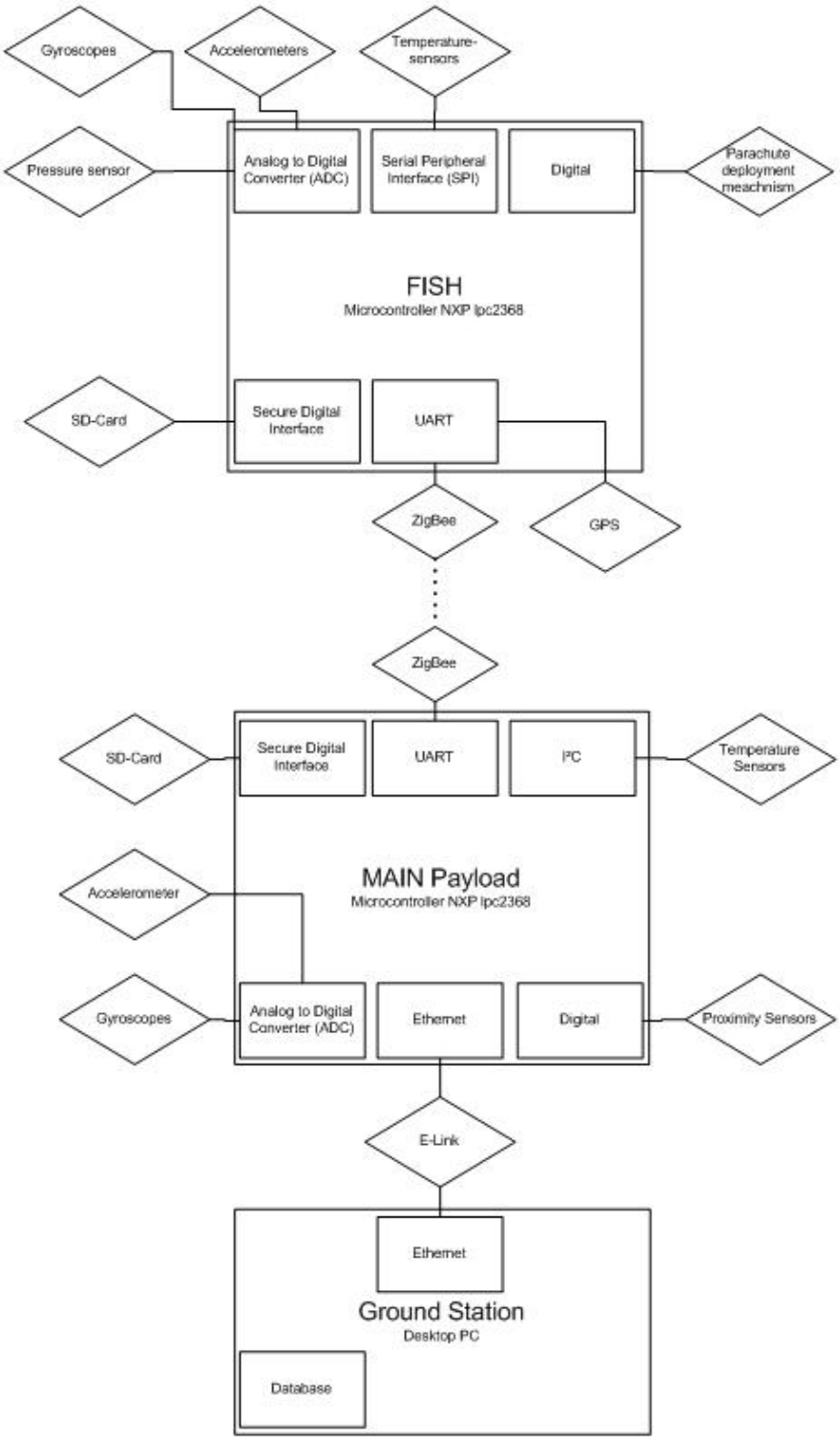



**Figure 3.19 FISH, MAIN Payload and Ground Station Software System Design**

### 3.8.1 Operating System

During the execution of experiments several tasks have to be processed at the same time. These tasks are for example:

- Control of the free-fall (open bail, close bail)
- Control the system health (sensor malfunction check)
- Store sensor data (on local SD-Card)
- Transfer sensor data to ground station

For that reason it was decided to use a real-time operating system (RTOS). The advantage of choosing a RTOS is its deterministic behaviour. This means that the maximum execution time of all instructions is known. It allows writing functions that will execute in a pre-calculated amount of time.

During the free-fall experiment the time between opening of the bail (begin of the free fall) and its closing (end of free fall, begin of braking) is very critical. If a real-time operating system is used, the internal task scheduler allows a guaranteed maximum time between opening and closing even if other parallel tasks are running at the same time (like a large data transfer).

Normally, real-time operating systems are very costly because of the complicated design of a deterministic task scheduler and the necessary certification process.

However, there exist uncertified free RTOS. One of them is FreeRTOS [24]. There exist ports to several different microcontrollers, including the one used in this project.

One disadvantage is that real-time scheduling always reduces the processing power of the microcontroller. For that reason the microcontroller has been selected with margins for processing power.

### 3.8.2 Programming Language

When using FreeRTOS the list of supported programming languages is rather short. The most frequently used language for the lpc2368 is the C Programming Language. For that language a variety of Integrated Development Environments (IDE) exist, simplifying the development process.

The program for both the FISH and the main payload will be written C. It will consist of different kinds of tasks that run in parallel (pre-emptive multitasking):

### 3.8.3 Tasks

Atomic tasks:

This type of task consists of one singular action (e.g. “READ_TEMP_SENSOR_1”). They can be executed in any order independent of any other tasks that might be executed at the same time.

#### 3.8.3.1 Composed tasks:

Composed task consist of a set of atomic tasks and therefore execute a sequence of tasks. Some composed tasks cannot be executed simultaneously. An example composed task is for example “OPEN_BAIL”. It consists of the atomic tasks:

- MOVE_REEL_TO_BAIL_OPENING_POSITION
- CHECK_REEL_SPEED and
- OPEN_BAIL_100_DEG

#### 3.8.3.2 Control tasks:

The most difficult tasks implemented in the reel.SMRT software are control tasks. They consist of a sequence of composed tasks that control certain behaviour of the experiment. A control task is for example responsible for detecting a malfunction in the reel brake. It consists of the following sequence of composed tasks:

- If “BAIL_CLOSED” and “REEL_SPEED = 0”
- If “FISH_RELATIVE_ALTIITUDE_CHANGE = 0”
- = no_malfunction

These tasks do not necessarily have to be one capsulated task. Single direction operations (like reading a sensor value) can be executed in an additional task. The sensor value is then stored in a global variable.

### 3.8.4 Ground station

The ground station mainly consists of graphical user interface (GUI) that helps the ground crew to supervise the performance of the experiment during the flight. It shows the GPS position of the gondola on a map. In addition, the status data of the experiment is displayed including the position of all moving parts (bail, reel, FISH). If sensor data is downloaded during the flight, its values are displayed in graphs so that unexpected behaviour can be identified very quickly.

The ground station also supports issuing telecommands to the balloon to be able to work problems that may occur during the automatic execution of the experiments. Those telecommands could be:

- OPEN_BAIL_3sec
- SLOW_REEL_2sec
- CLOSE_BAIL

The ground station software is run on a standard Personal Computer. The data from the E-Link system will be fed into the computer via the standard Ethernet interface of the PC.

In addition to the visualization of the experiment parameters, all downstreamed sensor data is stored in a database on the harddrive of the PC. This allows easy data analysis beginning directly by the end of experiment even before the landing of the gondola.

The maximum size of the database will be reasonably small. Even if 20 slow reel experiments are performed during the flight (with about 10 sec * 288 kBit/sec) the maximum size will not reach 12 MBytes. Therefore it is not necessary to use a high performance PC.

### 3.8.5 Safety

Several functions are implemented to avoid any danger from the experiment. Some of the safety functions are:

- Watchdog timer (restarts the microcontroller in case of an infinite loop)
- Brownout detection (low battery power does not lead to unpredictable behaviour)
- Sensor malfunction detection (partial recovery possible due to redundant sensors)
- Real-time operating system (deterministic behaviour of the reel control)

## 3.9 Experiment Control System

### 3.9.1 Electronic design

3.9.1.1 MAIN Payload

*Reel motor, Line Guide motor*

These motors are to be the most important in the system: responsible for reeling back the FISH. The specifications given by the mechanical subsystem were that the motor needs to be of the nominal power of 30W output power (on the shaft) which means that the input power will be some 60W (taking into account 50 % efficiency in the whole electromechanical system). There are two possibilities for the motors: brushed or brushless.

Generally speaking brushed motors are cheaper than brushless mainly because of the control system which is much easier to implement. The selection is also much wider than for brushless motors. The disadvantage is the mechanical commutation whose life-time is significantly reduced when operating in thin atmosphere. Nevertheless, significant testing was conducted regarding the quality of the commutation especially for martial missions (whose atmosphere is very similar to that encountered at 30-40km altitude). These tests showed that (28) even stock brushed motors could handle up to 40 million revolutions in thin atmosphere (0.8 kPa). Since our objectives call for only several thousands of revolution, the use of brushed motors may be possible. Another drawback of brushed motors is the higher amount of EMI which may not be acceptable.

Brushless motors are more expensive than the brushed motors and also the selection is limited. The advantages are in their lower EMI and their electronic commutation.

At this point the electrical subsystem is design to control brushed motors; however, the possibility of using brushless motors have not been ruled out and the final decision is to be made based on the feedback provided at the PDR.

The motors for which the electrical subsystem is designed for 24V with the maximal stall current of 30A. These parameters should be adequate for most of the 60W brushed motors rated at 24V.

*RC Servo Motors*

These motors were selected for the particular task of flipping the bail and hence, initiating the drop. The electrical subsystem is design to handle 1A of continuous current for servos rated at 5V. The electrical subsystem is design for two such servos, for redundancy purposes. The control method is to be CPM (Code Pulse Modulation).

*Battery pack*

High Power Polymer Li-Ion Pack: 11.1v 2200mAh was selected as a primary source of energy on the MAIN Payload. In order to keep the weight as low as possible and also to deliver the stall current for the reel motor when engaging the brake, the selection was made for this power demand. This power supply is to be able to deliver up to 40A, which will be further limited by PCM (printed circuit module) to a value corresponding to the stall current of the motor.

Since every motor will be rated at 24V, two packs in series will be required as a power source for the motors.

Since the power supply is essential for proper functionality of the system, both power packs are to be connected in parallel providing enough energy for the mission and also providing redundancy.

The PCM which will be used for the protection must be able to protect the battery pack from deep discharge, overcharge and over current. The example of a possible PCM is listed in the components list, see Appendix A.3. This PCM is qualified for the use with Polymer Li-ion battery packs and it limits the current to the value of 40A. Nonetheless, the final selection of the PCM is to be done with the respect to the stall current of the motor. The battery is to use connectors to be easily interfaced to the motors and the PCB.

*Power Supply*

The most important requirement for the power supply is to keep the power electronics and motors galvanically isolated from the other electronics. This is

necessary for any serious measurements in the system and also it protects sensitive electronics from being damaged by potential spikes caused by inductance load. This requirement calls for using isolated power supplies, isolated (intelligent) switches for driving the motors and if any measurement is to be made on the power electronics' side, it needs to be coupled to the microcontroller via opto-couplers or isolated operational amplifiers.

*Dual 5V Switching Regulator*

The basic power supply which is +24V needs to be stepped down to a suitable voltage level for the microcontroller and also for ZigBee and other sensors. Since the voltage drop is almost 20V and the output current will be in terms of hundreds of mA, a switching power supply needs to be implemented. The selected DC/DC converter is FD12Series which is a switching dual power supply capable of delivering 1.2A per rail. The current is to be adequate for providing energy for the GPS, microcontroller, ZigBee, IMU unit, and other sensors. The advantage of having in the system negative voltage rail is the option of using dual supply operational amplifiers.

*Linear 3.3V Low Drop Regulator*

Since the microcontroller, ZigBee needs +3.3V, another regulator needs to be added to the system. The linear LD1117A is a 3.3V voltage regulator capable of delivering 1A of continuous current with maximal voltage drop of 1.15V. This regulator is to be connected to the +5V rail of the dual power supply.

*Switching Power Supply +5V*

There are to be two RC servos, each rated at 5V with the maximal current of 1A. Because of the requirements to have galvanically isolated power electronics and the main electronics, the power supply has to be connected directly to +24V. Since the voltage drop is to be 20V, the preferable solution is to use switching single power supply; this is to be achievable by using DE-SW050, which is a 1A 5V switching voltage regulator.

*Power Electronic*

Power electronics are to be galvanically isolated from the main electronics. The switch for controlling the motor is to be an international rectifier high side switch IPS6021PBF. This switch features isolated logic ground from power ground and it is capable of delivering up to 32A at the maximal voltage of 39V.

The control of the RC servos is to be done by Code Pulse Modulation. The opto-isolation is done by general purpose opto-coupler MCT6. The turn on and off time is 0.0024ms which is far less than the expected modulation (20ms period with 25%-75% duty cycle).

Measurements of the current and the monitoring of the battery level is to be accomplished by Isolated Linear Sensing IC HCPL-7520.

*Sensor Package*

The MAIN Payload is to be equipped with 4 hall sensors, two of them with radiometric output, two with a digital one. The digital ones are to be used to monitor the distance of braking after the brake is activated. The hall sensors with radiometric output are to be used for monitoring the position of the bail. The bail is to be equipped with two small magnets, when these two magnets are above the hall sensors, the output will be maximal and the bail is to be stopped in this position. The fourth digital hall sensor (proximity switch) is to be used for monitoring the status of the bail. This switch is to be high when the bail is open and hence one of the magnets on the bail is in the close proximity of the hall sensor. The hall sensors to be used are A1321 (radiometric output) and A1101 (digital ones)

The monitoring of the fish in the box is to be achieved by the infrared proximity sensors. One of the possibilities is to use GP2D120. The output of this sensor is proportional to the distance between the object and the sensor. The sensed distance is anywhere between 40mm and 300mm. The interface between the sensor and the microcontroller is to be either analogue (the voltage divider and voltage follower needs to be implemented) or the analogue voltage is to be compared with certain threshold and the digital output is to be used. The advantage of this approach is that one of the analogue inputs is to be preserved; on the other hand, the selection of the threshold must be done such that the information regarding position of the fish is reliable. There are to be three proximity sensors, one in the bottom upper part of the box to sense when the fish enters the box, the second in the upper part of the box to sense when the fish is just about to hit the reel and the third one in the lower half of the box for redundancy.

The absolute position is to be measured by Garmin GPS 35. The supply voltage for this GPS is +5V and the maximal current is 140mA. The advantage of using this GPS is unlimited altitude information. The information from GPS on the MAIN Payload and the GPS data from the FISH is to be used when evaluating relative position between the gondola and the FISH when reeling back.

The MAIN Payload is to be equipped with the inertial unit. This unit consists of three ADXRS300 gyroscopes and two two-axis accelerometers of type ADXL210. The analogue output values of these sensors are fed into a 16-Bit ADC (ADS8344). In addition, the internal temperature sensors of the gyroscopes can be read out (the accelerometers don't have an internal temperature sensor). Since the ADC only has eight inputs only one port is left for the temperature reading (3 inputs for the gyros, 4 inputs for the accelerometers). To choose the temperature source a multiplexer is used (CD4067BE). The pin-out of the output connector is as shown in Figure 3.20 and Table 3.15.

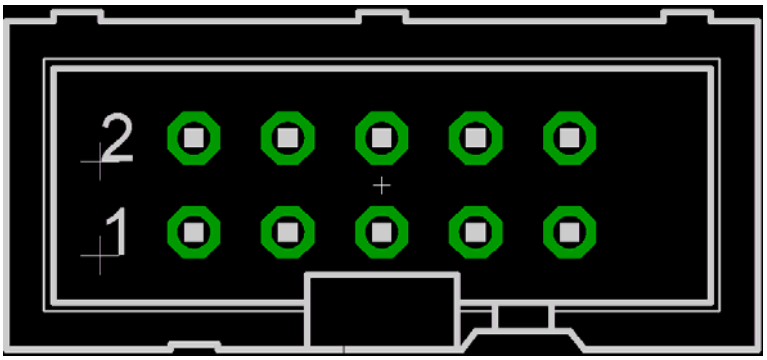



**Figure 3.20 CD4067BE Connection Pin-out**

| Pin | Function |
|---|---|
| | |
| 1 | Supply voltage GND |
| 2 | BUSY (Statussignal AD-converterr) |
| 3 | TEST (gyroscopes) |
| 4 | DATA OUT |
| 5 | Multiplexer output select A |
| 6 | DATA IN |
| 7 | Multiplexer output select B |
| 8 | DATA Clock |
| 9 | Reference voltage (2.5V) AD-converter |
| 10 | Supply voltage VCC |

**Table 3.15 CD4067BE Connection Pin-out**

This unit is to be interfaced with the microcontroller via 7 general IO pins. Since this unit also requires 2.5V reference, the system is to have precise TI REF5025 buffered by an operational amplifier.

In order to monitor proper operation of the reel motor, there is to be temperature sensors to monitor temperature of the motor and also current sensing to monitor the torque. In case the wire gets tangled, the torque is to increase and the reeling may be stopped and the line guide motor used to reel the fish back.

Another temperature sensor is to be used for monitoring ambient temperature of the box. These sensors are to be MCP9800, with the accuracy of 2°C within the range from -20 °C to +85 °C. These sensors are to be connected to the microcontroller by $I^2C$.

The reel motor is to be equipped with an incremental optical encoder with a sufficient number of turns probably more than 250 turns per channel is to be sufficient in order to maintain accuracy to less than 2 degrees which should be enough to position the bail. The incremental optical encoder is to have 3 channels, two shifted by 90 degrees and each having 250 pulses per revolution and the third one to have one pulse per revolution.

*Microcontroller*

The microcontroller used in the MAIN Payload is NXC2368 and it is identical as the one in the fish.

*Power Budget – MAIN Payload*

The most significant energy consumption comes from the motors and mainly the reel motor. The reel motor is to be used for 10 drops each lasting 120s based on specification from mechanical subsystem. The motor is to be 60W rated input at 24V. One motor which corresponds to the three parameters is RE30 (Maxon, re-max). This motor is 60W rated at 24V. The continuous current for this motor is 3.44A. If the motor is to be operated for 20 minute, it will consume 1.14Ah. The battery pack has to provide this energy. The battery pack in the low temperature is to be having reduced capacity (75%). If only two 11.2, 2220mAh packs are used the total energy is to be 1.65Ah. In order to ensure correct operation during the whole mission, the four battery packs are to be used in the main payload. The total energy will be 2.2*2*0.75=3.3Ah, which is three times more that the power required for the motor.

The electronics themselves will not draw more than 500mA in steady-state (microcontroller, IMU, GPS and Zigbee).Moreover, since there is to be switching power supply, the consumption is to be effectively decreased by the factor of 4 (24/5).

*Power Budget – FISH*

The Fish uses two SAFT batteries (SAFTLSH 14 "Light") rated at 3.6V. The maximal current is up to 1.3A and the capacity is 3600mAh. Table 3.16 below shows the power budget for the components we are currently using.

| Unit | Current Consumption(mA) | At voltage(V) | Power (mW) | Power disipation(mW) | Units | sum (mW) |
|---|---|---|---|---|---|---|
| Microprocesor | 125 | 3.3 | 412.5 | 1500 | 1 | 412.5 |
| Colibry M8002.D | 0.4 | 5 | 2 | 0 | 3 | 6 |
| ADS1274 | 50 | 5 | 250 | 285 | 1 | 250 |
| ADS1274 | 18 | 3.3 | 59.4 | 0 | 1 | 59.4 |
| ADS1274 | 0.15 | 1.8 | 0.27 | 0 | 1 | 0.27 |
| HMC6352 | 1 | 3.3 | 3.3 | 0 | 1 | 3.3 |
| LIS3L02AQ3 | 0.85 | 3.3 | 2.805 | 0 | 1 | 2.805 |
| Xbee | 45 | 3.3 | 148.5 | 0 | 1 | 148.5 |
| | | | | | Total | 882.775 |
| Batteries | Voltage(V) | Current(Ah) | Number of units | Total Power (Wh) | | |
| SAFTLSH 14 "Light" | 3.67 | 3.6 | 2 | 26.424 | | |
| Total amount of current is 250mA | | | | | | |
| The power supplied by the batteries is 3600mAh | | | | | | |
| so the system could be running for bout | | 14.4 | 14 hours | | | |

**Table 3.16 Power Budget for the Components of the FISH**

The projection for the operational time of the fish is more than 14 hours.

*Electrical interface*

The electrical interface between the main payload and the e-link is to be Ethernet, physically connected via MIL-C-26482-MS3116F-12-10P.

*Electronic Subsystem – FISH*

The Free-Falling Instrument System Housing (FISH) is a part of the reel.SMRT payload that will be dropped into free-fall from the MAIN Payload in the hopes of achieving some instants of microgravity.

The electronics inside this payload are one of the most important (and expensive) parts of the whole mission, as they will be the ones to be sensing the accelerations

and motions of the system during free-fall, and will be the ones to be able to detect if some instants of micro-gravity are achieved, and for how long they happen.

These electronics are comprised of the following mayor components:

**LPC2368 Microprocessor**: This is a single chip 32 bit microcontroller, based on a 32 bit ARM7 CPU, which has: 512kB flash, SPI, $I^2C$, 10 bit ADC, and four UARTS, among many other peripherals. This makes it ideal for our application as it has plenty of ports and interfaces that will enable the system to be able to handle multiple sensors and be able to store the data as well as transmit it to the wireless module so it can be backed up and see the status of the mission in real time.

**Colibry 8002.D Accelerometer** is a MEMS capacitive accelerometer sensor that has an excellent bias stability that will enable the system to accurately measure the acceleration, especially when approaching the state of microgravity. This sensor is a 1 axis accelerometer, so 3 units have been included in the design to be able to sense X, Y, and Z.

**ADS1724 Analogue to Digital Converter** is a quad, simultaneous sampling, 24-Bit Analogue-to-Digital Converter. This particular converter was chosen because it can measure 4 channels simultaneously, allowing us to be able to get the data from all the high precision accelerometers with a 24 bit resolution and at very high sampling speed (up to 128 kSPS). It also can communicate with our microprocessor via SPI and Frame-Sync.

**Xbee Zigbee Module** is a RF module that meets the IEEE 802.15.4 standards and works in the 2.4 GHz frequency band, and although we know that channels 2-14 are forbidden to use during the mission, we still have some few remaining channels to be able to communicate the FISH with the MAIN Payload. These radio modules have very low power consumption and have a good range that will hopefully be able to communicate both payloads for the whole mission.

In addition to these very important components, other components were added to add redundancy to the system in case of failure as well as to have more data available to be able to know with more detail, what happened during the whole mission. These components are a set of three ADXR150 Gyros, a HMC6352 Compass, a Phoenix GPS and a LIS3L02AQ3 three axis accelerometer.

*Features of FISH*

- Redundancy of data acquisition: there are two sets of three axis accelerometers that will be measuring the acceleration of the FISH at all times, so in case the main accelerometer pack fails, the backup, that although not as accurate, will be able to still send some good data.
- Redundancy of data storage: The FISH will be saving all the information on the internal micro SD card, and also transmitting it to the main payload,

which will store it and try to retransmit to ground station, this way having the data stored in 3 different places, to avoid losing it all if one of the storage systems fails, and even in the worst case scenario, that the internal FISH micro SD card failed, at the same time that the wireless link failed, the microprocessor itself had 512 kbytes of memory available to enter an emergency mode that would be saving all the recorded data, while the wireless link or the internal memory could be recovered.

- Safety: An emergency parachute deploying system will be monitoring the FISH at all times, ready to be deployed if the tether would fail.

*The system in a nutshell*

The FISH is a system which will be acquiring the acceleration data with three Colibry 8002.D accelerometers (one for each axis x, y and z) via an ADS1724 Analogue to digital converter, that will send the data acquired to the LPC2368 microprocessor. The microprocessor will also be receiving analogue data into its internal ADC from three Gyros, and one extra three axis LIS3L02AQ3 accelerometer that will be used as a backup in case the other accelerometer would fail. A Phoenix GPS receiver will communicate with the microprocessor via a serial UART and will be used to know the position of the system and the exact height and distance of the FISH with regards to the MAIN Payload. A HMC6352 Compass is interfaces via $I^2C$ to know the orientation of the FISH when it's docked into the main payload, as there will be a magnet inside that will be used for reference. The microprocessor will be storing all this data into its on-board micro SD memory card, along with a timestamp. At the same time, it will be communicating with the MAIN Payload and sending as much data as possible to be backed up, and also to be retransmitted to the ground station for immediate analysis and system status updates. In case of an emergency, the system, with the aid of all these sensors will be able to detect if the tether that joins the FISH to the main payload has, for some reason, broken, and will activate an emergency parachute deployment mechanism to avoid turning the FISH into a threat to anything or anyone on the ground.

*Current Status*

As it stands at the moment, the schematics for most of the FISH have been made (see Appendix E.1) with the exception of the electronics for deploying the emergency parachute system are still missing.

*Future Work*

When these schematics have been approved by the group of experts in PDR or upgraded by feedback from them, the parts will be ordered and the PCB boards (1 or 2 circular PCB boards) will be designed and sent for manufacturing. By the time

they are ready, and the parts have arrived, the system will be assembled in the Electronic Laboratories of the Helsinki University of Technology. And will later on be delivered to the Kiruna Space Campus for testing.

### 3.9.2 Data management

#### 3.9.2.1 Communication FISH-payload

In the FISH, two categories of sensors can be found:

- Scientific sensors
- Control sensors

The purpose of the scientific sensors is mainly to measure values needed for post-processing. Those sensors are:

- Accelerometers (two in each of the three body axes, see Electrical)
- Gyroscopes (about all three body axes)

The control sensors are only used to provide feedback information needed to control the experiment. Those sensors are:

- Pressure sensor
- GPS

However, in degraded operation (failure or malfunction of one or more sensors) the data of the scientific sensors can be utilized to enable a safe execution of the experiment even when some subsystems are not functioning as expected.

All sensor data is stored on a memory card (SD-card) continuously during the experiment. In addition, all data is transmitted to the payload using a ZigBee compatible link. However, the transmission of all data cannot be performed in real-time, since the data rate of ZigBee (115,200 kBit/s maximum) is too low for the large amount of data generated by the sensors (~174kBit/s) (see Appendix S.1 “Calculation of Net data rate of FISH sensors”).

Therefore, during execution of an experiment (either slow reel or free-fall) the amount of transmitted sensor data is reduced. As soon as the FISH is back in the payload bay the remaining data is transferred to the payload’s storage.

In general the communication between FISH and main payload is bidirectional: sensor data are sent from the FISH to the main payload and experiment status

data messages (like “slow reel in progress” or “emergency recovery mode activated”’) is transmitted from the main payload to the FISH. But if one direction fails to function properly, the experiment can be continued in unidirectional mode. All status data messages are acknowledged by sending the data message back to the main payload.

#### 3.9.2.2 Error detection/correction

The ZigBee modules do not provide any error detection or error correction algorithms. Therefore the quality of the data transmission is enhanced by adding a cyclic redundancy code (CRC) error detection part to each transmitted block of data. If an erroneous sensor data block is detected on the main payload side a status data message is sent to the FISH including the time stamp of the sensor data block that needs to be retransmitted. Status data messages received from the main payload are protected by a CRC part as well. But they are not requested again. Instead, if no acknowledge data message is received in a certain time by the main payload, the sensor data message is retransmitted.

#### 3.9.2.3 Communication main payload – Ground station

Similar to the FISH, the scientific sensors located in the main payload are accelerometers and gyroscopes. The values measured by these sensors are stored on a local flash memory (SD-Card). In addition, all sensor data received from the FISH is stored on that SD-Card as well.

As almost the same amount of data is generated by the main payload sensors as by the FISH the total data rate to the SD-Card nearly doubles (2 x ~174kBit/s = ~288 kBit/s). But still this data rate is well below the maximum data rate a SD-Card can handle (~08 MByte/s).

The main payload also houses the main microcontroller, which controls the entire experiment. In addition to that it also controls the communication between the reel.SMRT experiment and the ground station.

For that purpose, the balloon’s E-Link telemetry system is utilized. It supports data exchange with the ground via an Ethernet connection.

This connection is used to download status information to the ground station to be able to supervise the experiment from the ground. If necessary, the uplink capability of the E-Link connection is used to send telecommands up to the experiment. If the payload performs as expected, this is not necessary since an automated sequence is planned to be used to execute all parts of the experiment autonomously.

Depending on the bandwidth available on the Ethernet link, it is planned to send down at least parts of the acquired sensor data during the flight. This is not

needed but it helps to bring the valuable data into a safe place so that a satisfying data analysis can be done even if the whole experiment gets damaged.

Without the downlink of sensor data, the data rate for the downlink is very low. During the reeling process, the number of status messages can go up to 15 in about 5 seconds. With a status message length of 20 Bytes, this sums up to about 60 Bytes/s.

The uplink telecommands are executed manually reducing the number of messages to about 1 per second or 20 Bytes/s.

If the downlink bandwidth is available, all sensor data could be downloaded with a data rate of ~300 kBit/s. When missing parts have to be retransmitted, this value can go up to about 600kBits/s.

All status information is transmitted using TCP/IP packets. This allows the use of the error detection/correction/ functionality of TCP/IP. If the delay time of the telemetry link is very high (> 1 sec) the sensor data can also be downstreamed using the UDP connectionless packet type. Then however, no error correction functionality is available.

### 3.9.3 Radio frequencies

For the communication between FISH and MAIN payloads, ZigBee radio modules are used to transmit in the ISM band at 2.4 GHZ. According to the “Bexus User Manual v5” channels 2 – 14 are not allowed to be used during the flight, the ZigBee modules will be configured to only use channel 16 of the ISM band. During RF tests, it should be obvious if the module interferes with the blocked frequency range. In this case, a second short range transceiver module can be used (RT868F1). It uses the frequency range of 868 MHz which is far away from any frequencies used on the balloon. The big disadvantage is, however, that the transmission range is much shorter. This means that not all the data from the FISH can be uploaded to the main payload in real time. This can only be done after the FISH is reeled back up and needs some time. As a consequence, the number of sequences could be influenced by that, because a new drop can only be started after all sensor data from the previous drop is transmitted to the MAIN payload.

The data rate between FISH and MAIN payload is very low, most of the time. Only during reeling experiments (slow reel or free fall) the link will be used heavily. During that time and shortly after the drop the data rate can go up to 180 kBit/s.

The ZigBee compatible modules that will be used are the Xbee modules from Maxstream [25]. They are connected directly to one of the UART ports of the microcontrollers.

## 3.10 System Simulation

The purpose of the reel.SMRT system simulation is to determine the feasibility of the system both on a small scale as being conducted in this experiment, and on a large scale with increased drop distance and payload parameters.
In this way, requirements Req.F.9 'Investigation the feasibility of the system as a microgravity platform' and Req.F.10 'Assess the drift of the FISH during a drop and its consequences on the whole system and the measurement accuracy' shall be met.
The simulation shall thus model the dynamics and kinematics of the FISH, to determine the acceleration and position behaviour. Then, the aerodynamic behaviour of the FISH shall be simulated both for this experiment and as a feasibility investigation for larger scale models. The simulation shall also serve to justify sensor accuracies and be used to investigate the friction in the system and the line. The simulation shall build upon an initially simple model, as presented here, but be upgraded with more factors over time to include wind, reel oscillations and more accurate gondola perturbation effects. Following the mission, the model shall be improved upon using the mission data. This will enable the team to more accurately predict the performance of the system over different drop lengths and with variation of parameters.
From this analysis, the point at which the reel.SMRT system becomes a viable alternative to other low-gravity systems such as drop towers and parabolic flights shall be more reliably determined.

### 3.10.1 Aerodynamic Drag Force Simulation

A one dimensional aerodynamic simulation was created to calculated the relative g's that the FISH would be expecting if there was no resistance force produced the reel. This computes the limit on the microgravity performance of the system as imposed by aerodynamic drag only. It begins by computing the parameters for the current FISH design, and then computing the parameters for different weights and FISH shapes.

This simulation thus works via computing the instantaneous velocity of the FISH due to the force of gravity and the aerodynamic drag force. The Euler method was also utilised to calculate the position of the FISH throughout its flight.

This simulation involves the assumptions presented in Table 3.17.

| Parameter | Value |
|---|---|
| Mass | 1kg |
| Air density | 3-7 x $10^{-3}$ kg/$m^3$ (8) |
| $C_d$ | 0.8 (5) |
| Surface Area | 0.0177 $m^2$ (diameter 0.15m) |

**Table 3.17: 'The parameters for the present design of the FISH'**

The results for a 50m drop with a flight time of 3.1 seconds (Figure 3.18) the FISH should experience a maximum of 0.35 mg if all other forces are considered insignificant. This is obviously not the case because there will be friction forces and oscillations throughout the tether but it is a useful measurement because it gives the experiment a lower bound, not matter how frictionless the reel is the minimum g's that will be experienced is 0.4mg.

An analysis of a 20 second drop shown in Figure 3.22, demonstrates how this mechanism would compete with other types microgravity platforms (drop tower and parabolic flight) along with the number of g's the FISH experiences. One can see that the longer the flight takes the larger the g's get thus making it less competitive. This simulation shows that only with aerodynamic forces introduced onto the calculations then the maximum amount of the lower g experience that can be reached by this mechanism is approximately 16 seconds.

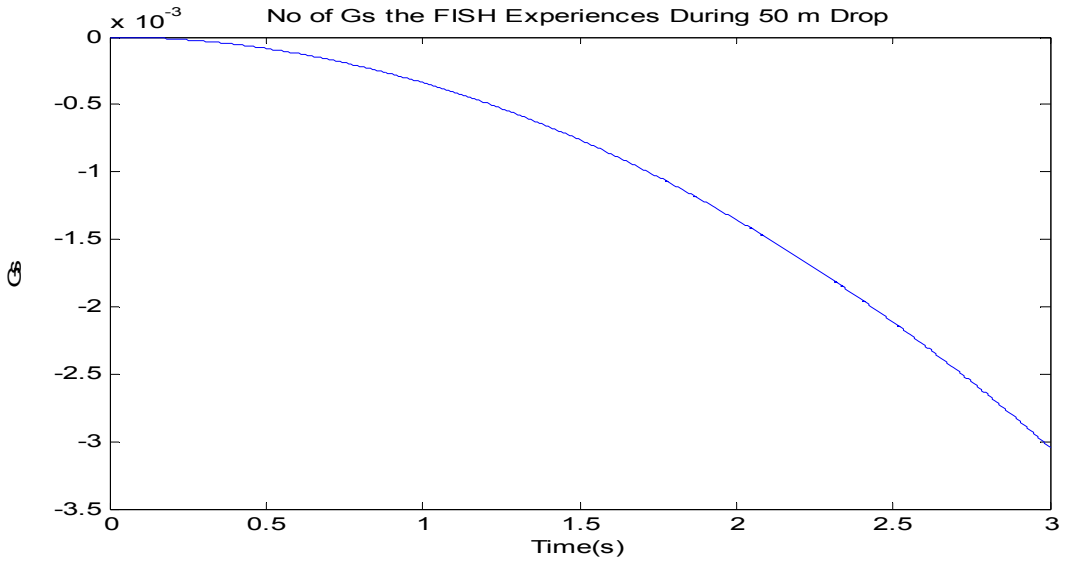



**Figure 3.21 G's experienced by the FISH on a 50m drop**

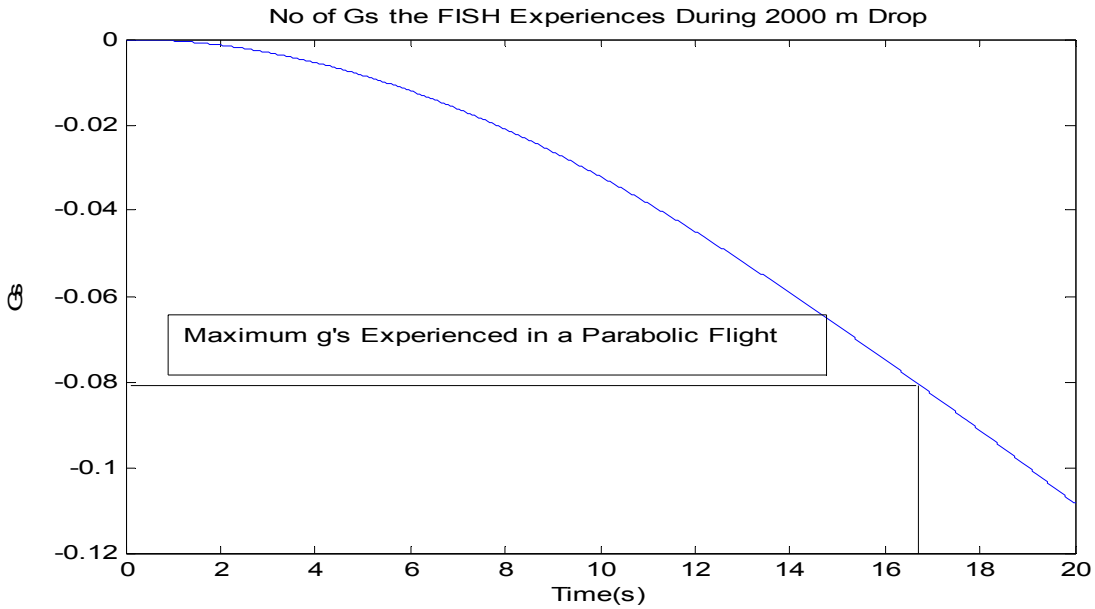



**Figure 3.22 G's experienced for a 2000m drop compared to a parabolic flight**

The above calculations were conducted with the parameters specified in the Table 3.17. For improving the low g experience an increase in the mass is needed along with a smaller cross sectional area and a more aerodynamic design. The masses main limiting factor will be the Balloon maximum payload (approximately 100 kg) or the strength of the reel. If the characteristics of the FISH were improved to the optimal conditions that are realistic and competitive (values stated in Table 3.18) then the flight profile looks like Figure 3.23

| Characteristic | Value |
|---|---|
| Mass | 40 kg |
| Cross sectional Area | 0.5m |
| $C_d$ | 0.5 |

**Table 3.18 The optimal characteristics for a up scaled version of the reel.SMRT**

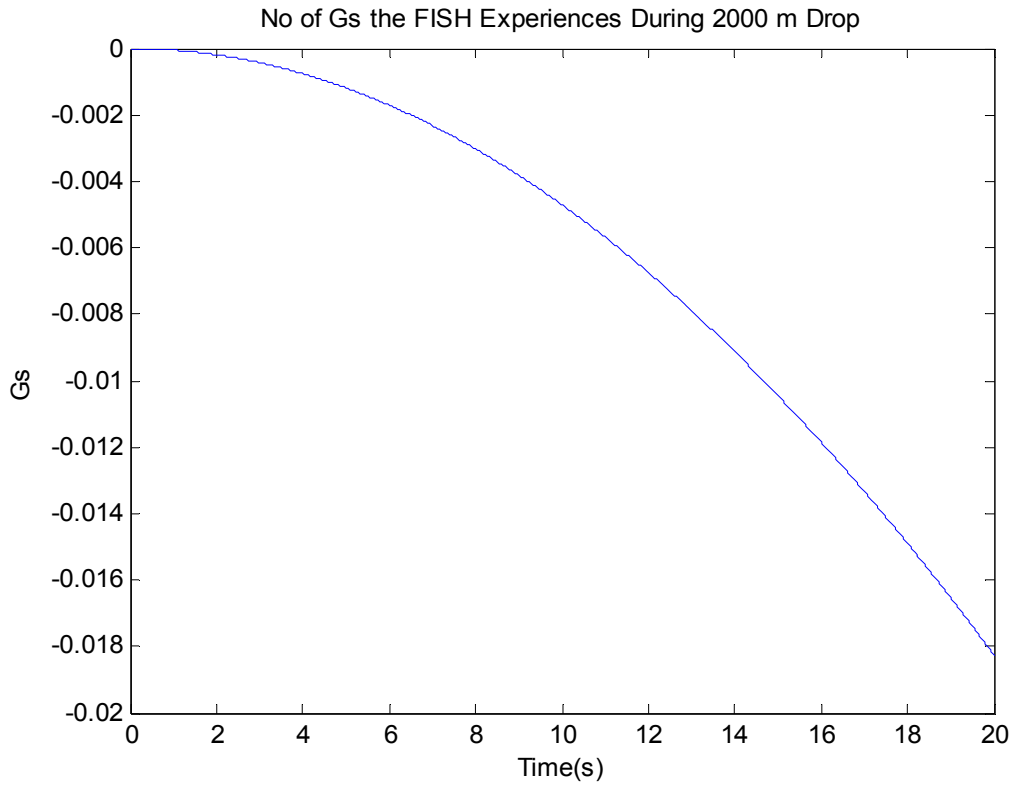



**Figure 3.23 G's experienced by a large scale FISH (40kg, Diameter 0.5m)**

The flight g's improve if this drop mechanism is increased to a full scale version with the maximum of 20mg experienced.

Figure 3.24 analyses the various configurations that are possible for the FISH and compare it to a parabolic flight conditions. The points represent on the graph the maximum flight time the FISH can achieve without experiencing g's larger than a parabolic flight. This threshold value is taken to be a maximum of 80mg.

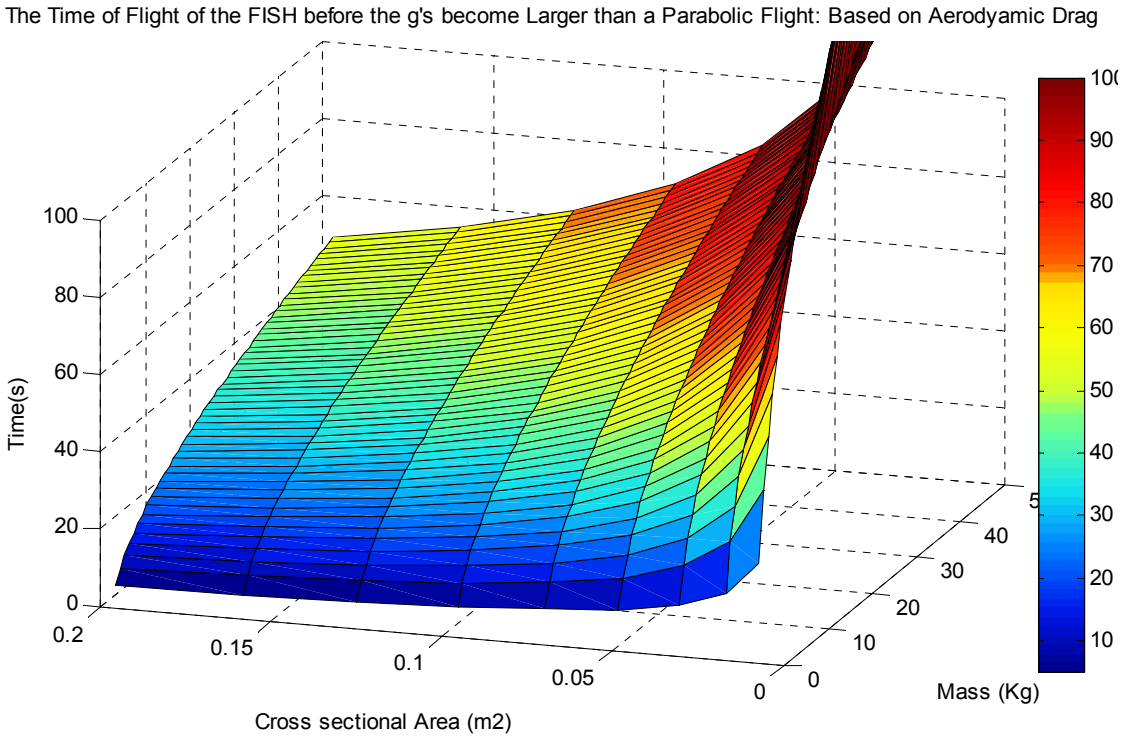



**Figure 3.24 The maximum competitive flight time a Drop payload can achieve if launched from a stratospheric balloon ($C_d$ = 0.4, air density = $5x10^{-3}$ kg/$m^3$).**

One can see that the larger the mass the longer the flight time of the FISH at a good g conditions but this normally will increase the cross sectional surface area and thus will reduce the competitive flight time. Note that this is the maximum flight time with no other forces on the FISH. If a friction force from the line was to be introduces then this competitive flight time will reduce. Thus the surface on Figure is the ceiling for Balloon Drop experiments.

In conclusion the Aerodynamic simulations have merely explained what should be expected if the FISH is dropped off the BEXUS balloon without a tether attached. For the present design there is an expectation that a minimum of 3 mg is will be experience thus helping the design of the accelerometer range. It has also been assessed the viability of an up scaled version of the reel.SMRT and after how long this method of achieving low g environments become less competitive compared to parabolic flights. For the largest FISH possible this should be able to produce a minimum of 30 seconds of a low g environment. Thus using a stratospheric balloon for a milligravity platform is a viable alternative compared to other methods.

### 3.10.2 Line and FISH Preliminary Simulation

3.10.2.1 Background

The preliminary simulation of the reel.SMRT system consisted of a free-falling mass, tether, aerodynamic drag and friction. The mass falling and force effect are normally analysed by Newtonian mechanics. Aerodynamic analysis has been clearly analysed and widely used in flight simulators such as the X-plane (29) and FlightGear (30). The most complicated part of the simulation is that of the tether. Various methods of string simulation have been done in the past. The method of finite element has been used by which the tether is divided into small pieces of mass and connected together by joint of constraint (31). A reasonable amount of research is available on analysis of tethered satellite systems. The spring-mass elements method has been use in MTBsim from the Delta-Utec tether company, for example (32).

3.10.2.2 Introduction

The initial simulation presented in this PDR documentation involves simulation of the dynamics of the FISH and tether with variation in gondola motion and line-limited speed. This is modelled on a physical engine to simulate the movement of the FISH relative to that of the gondola. The physical engine used in this preliminary simulation design is ODE (open dynamic engine) (33) which is easy for modelling and fast. Despite the coarse behaviour of such a simulation, the behaviour of the system by the force effect can be simulated correctly and so it was deemed sufficient for this initial investigation.

3.10.2.3 ODE physical engine

ODE is a free physical engine SDK under GNU Lesser General Public License and a BSD-style license. The concept of ODE is based on a “Rigid Body” and “Joint” system. This system consists of numerous rigid bodies, with each rigid body connected to the next by a joint.

Many parameters of the rigid body are time-dependent. These include: position (x, y, z), the linear velocity vector( $v_x$, $v_y$, $v_z$), body orientation (quaternion or 3x3 rotation matrix) and the angular velocity vector ($w_x$, $w_y$, $w_z$). The body also has its own mass, centre of mass and inertia matrix.

A joint is a relationship that is enforced between two bodies so that they can only have certain positions and orientations relative to each other.

When force is applied to a body, the force is transferred to another body by this joint. Once all forces have been considered and transferred, the engine calculates the new body states at the new time value through an integration achieved through small user-defined time steps.

The simulation result was able to be shown in real time graphical movement as well as properties graphs. A still frame from a reel.SMRT video simulation is displayed in Figure 3.25, showing the tether and a weighted mass simulating the FISH.

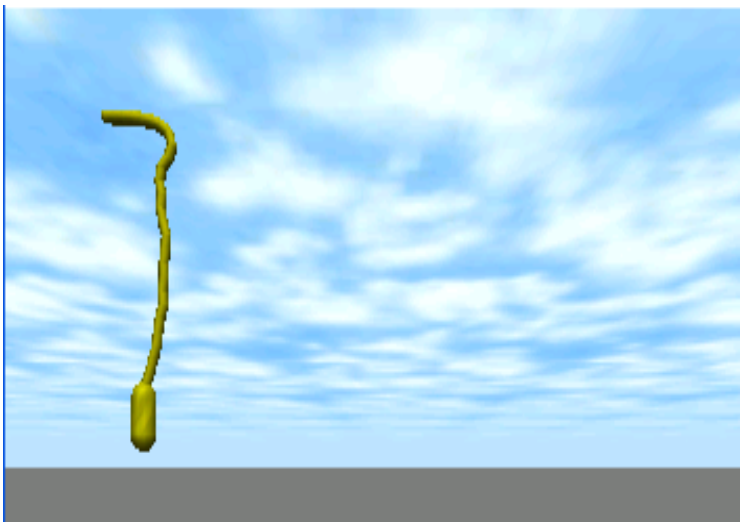


**Figure 3.25 Simulation environment graphical interface**

3.10.2.4 Preliminary System Model

In the reel.SMRT system, the main components for simulation of the FISH and tether dynamics were the FISH, tether and the MAIN Payload. The FISH and the MAIN Payload are rigid bodies which have been modelled directly in the ODE. The tether was modelled using numerous small mass rigid bodies connected by joints. The joint chosen was the “ball and socket” (Figure 3.26) joint, which can simulate twists, bends and oscillations within the tether.

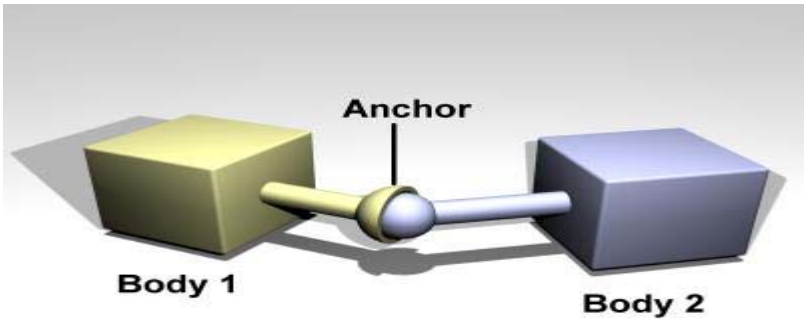



**Figure 3.26 Ball and socket joint.**

The increase in tether length associated with drop of the FISH was simulated by introducing new line rigid bodies at the MAIN Payload position as the line was

accelerated away from the MAIN Payload. The gravity used in the model was -9.81 m/s$^2$. The illustration of the process of adding a new rigid body, for no movement and then movement in the horizontal plane is shown in Figure 3.27.

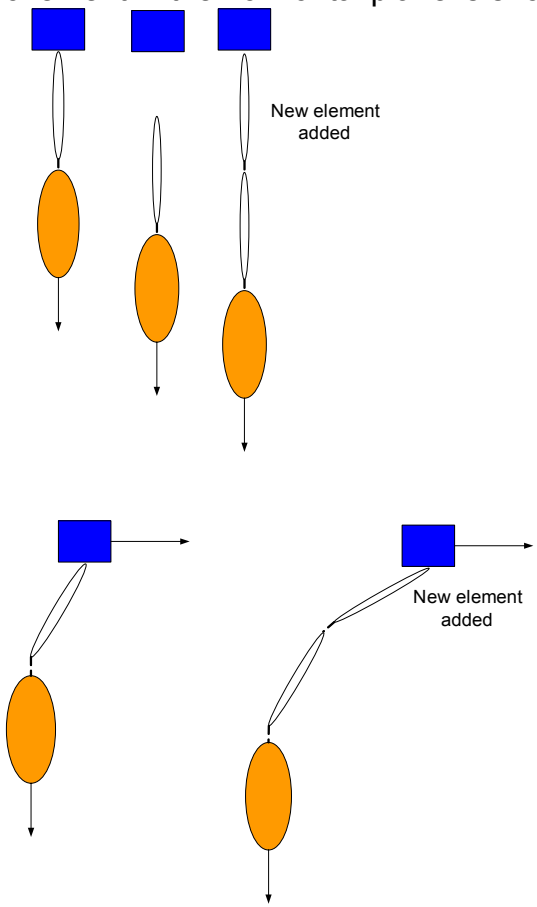



**Figure 3.27 Diagram show how the new element is added.**

3.10.2.5 Simulation result

As the inputs to the system are not known accurately at this stage, these being the gondola perturbations, maximum line-of-reel speed and system friction, arbitrary inputs are implemented in the simulation. Three separate line models have been employed. These are:

1. The new line element has initial velocity equal to the last element.
2. The new line element has no initial velocity.
3. The new line element has initial velocity which is limited to certain value.

The first model represents the situation where there is zero line friction and no limiting line speed on the system. The second model represents the situation

where there is a constant friction in the system, with energy used to pull down the line from rest. The third model is the same as the first, except that when the line speed reaches a maximum value it remains at that value. This simulates what would happen to the line should it reach it's maximum velocity and would remain at a constant velocity. This is relevant because it is the expected behaviour if the brake is applied at a low setting or if maximum line speed is reached within the system.

In each model, the MAIN Payload movement (input to the top of the line) was simulated in three patterns.

1. The MAIN Payload is not moving.
2. The MAIN Payload is moving in Y direction with constant velocity of 2 m/s.
3. The MAIN Payload is oscillated in Y direction with angular velocity of 4 rad/s and amplitude of 1 m.

The first simulation is to represent the ideal input case, the second represents a constant lateral motion of the gondola, such as that during stable phases of the mission, and the third represents gondola oscillation that may be incurred during the mission. The results for these nine simulations are presented in the next section.

**1. The new line element has initial velocity equal to the last element.**

Acceleration

In this situation, the movement of MAIN Payload has no effect on acceleration of the FISH in all directions (X,Y,Z) compared to no MAIN Payload movement. The acceleration in Z direction is constant at 1g (Figure 3.28). In X and Y direction the acceleration is constant at 0.

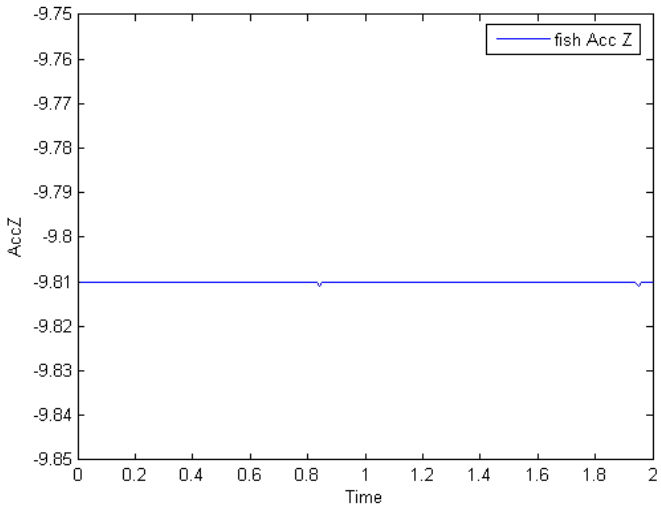



**Figure 3.28 Acceleration of the FISH in Z direction of in situation 1.**

Velocity

The movement of MAIN Payload has also no effect on FISH velocity in all directions (X,Y,Z) compared to no MAIN Payload movement as well as acceleration. The velocity in Z direction is increasing at constant rate (Figure 3.29). In X and Y direction the velocity is constant at 0.

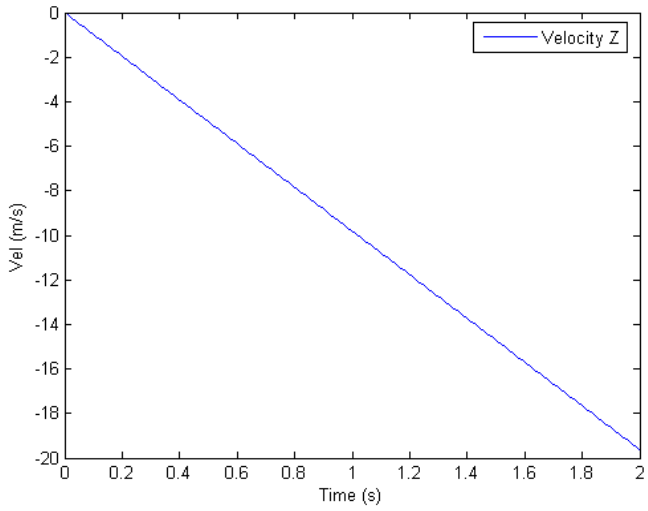



**Figure 3.29 Velocity of the FISH in Z direction of in situation 1.**

Position

The movement of MAIN Payload has also no effect on position of the FISH in all directions (X,Y,Z) compared to no MAIN Payload movement. The position in Z direction is in parabolic pattern which is the free-fall fashion (Figure 3.30). In X and Y direction the position is constant at 0.

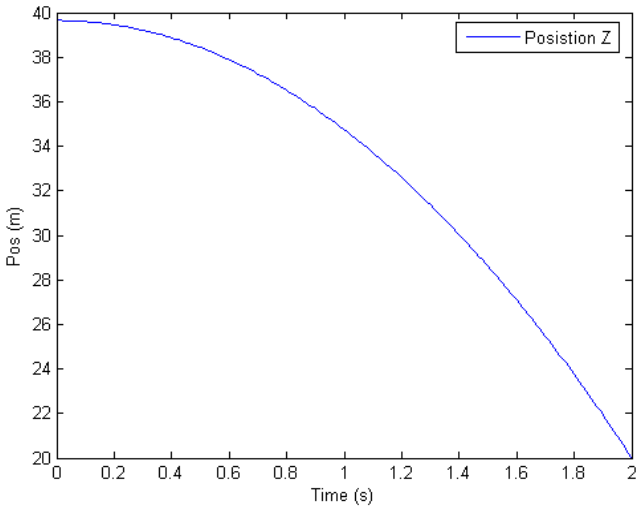



**Figure 3.30 : Position of the FISH in Z direction of in situation 1**

Angular velocity

The FISH has no rotation effect on the movement of MAIN Payload.

Conclusion

Thus, whilst the reel can produce has not reached maximum velocity or a velocity at which the friction retards the acceleration, the movement of the MAIN Payload has no effect on the movement of the FISH.

### 2. The new line element has no initial velocity.

In this situation, the FISH and line have to accelerate the new line element to move at the same velocity as the last element.

Acceleration

In this situation, even though MAIN Payload is not moving, the FISH still incurs a retarding force on its acceleration. In this case, the movement of the MAIN Payload has some effect on the acceleration of the FISH in the Z direction. In the X and Y direction the acceleration is constant at 0.

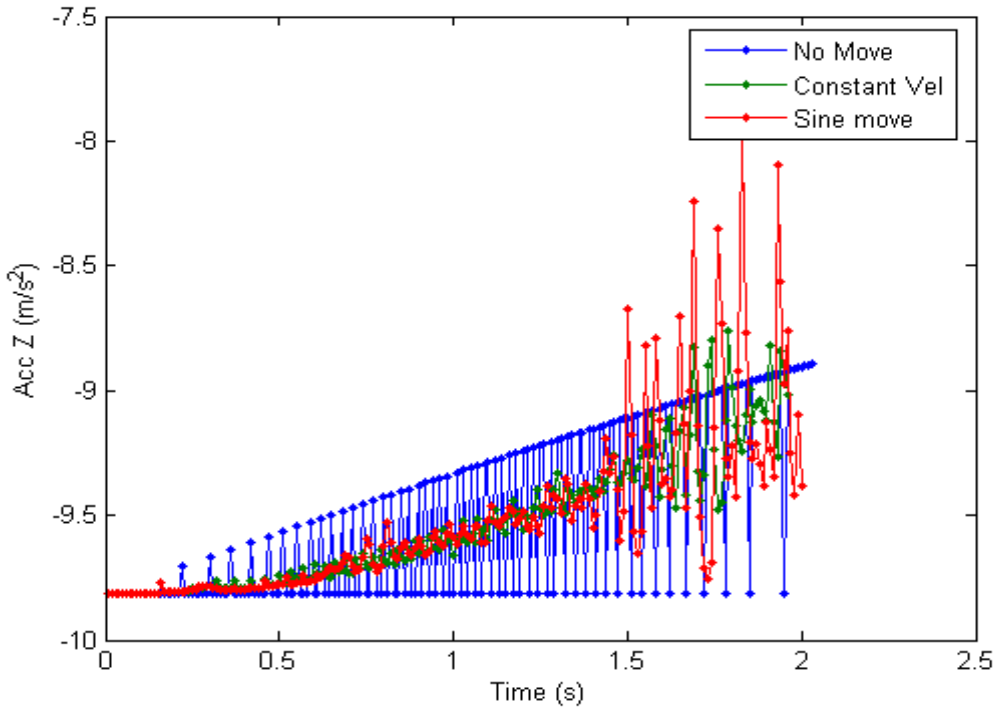



**Figure 3.31 Acceleration of the FISH in Z direction of situation 2.**

Position

The movement of MAIN Payload in the Y direction has some small effect on position of the FISH in Y direction compared to no MAIN Payload movement. In X and Z directions the position is the same in despite the input movements of the MAIN Payload.

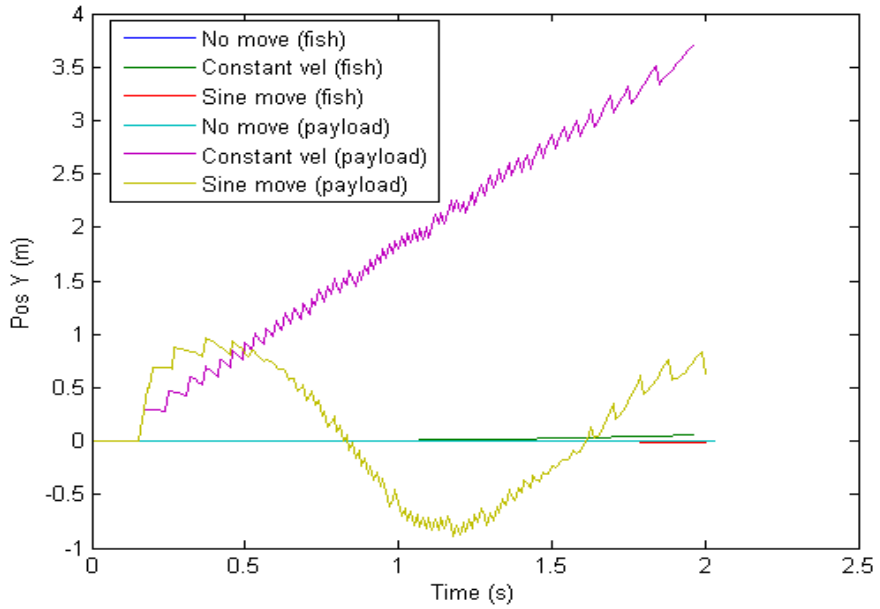



**Figure 3.32 Y position over time with curves based on input forces at the MAIN Payload.**

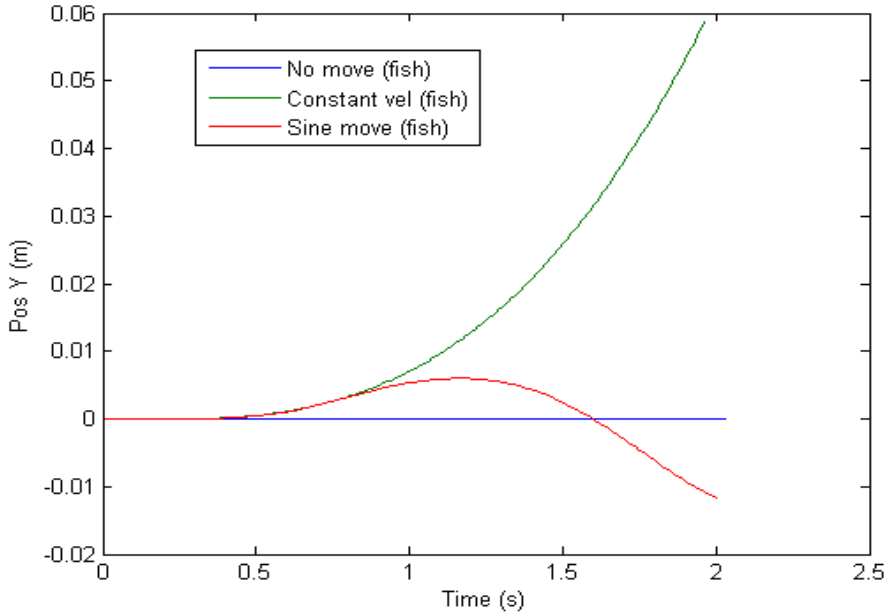



**Figure 3.33 Effect of the MAIN Payload movement in position of Y direction in situation 2.**

Angular velocity

The movement of MAIN Payload in the Y direction also affected the rotation of the FISH in the X direction. In the Y and Z directions, all the movement in the Y direction had no effect.

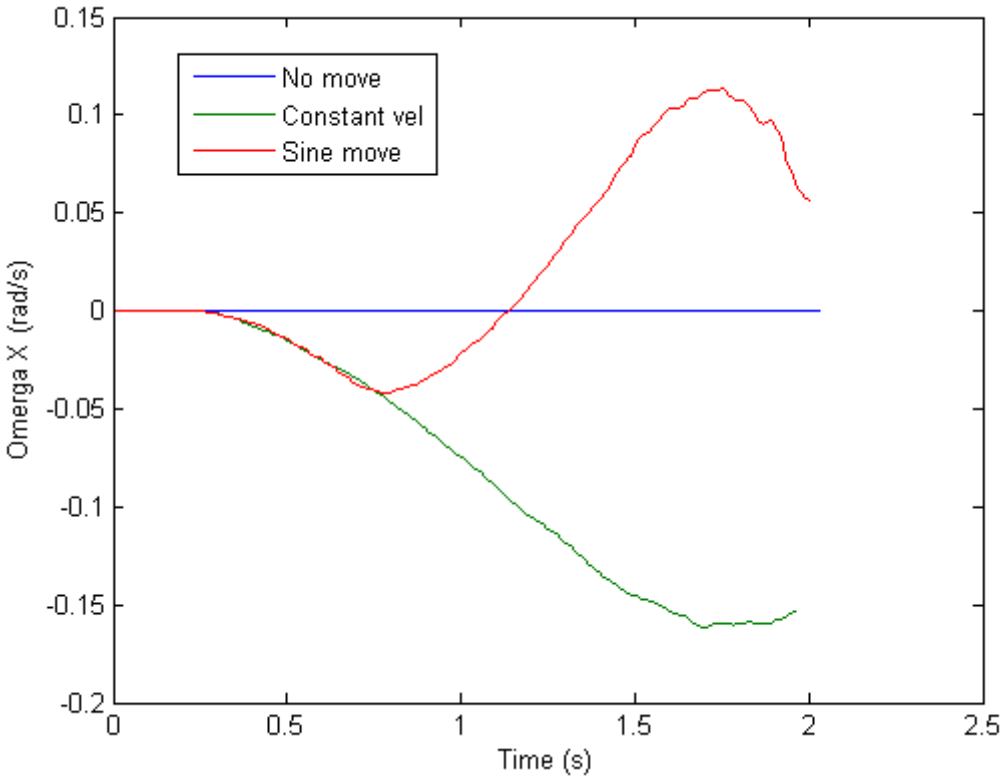



**Figure 3.34 : Effect of MAIN Payload movement on rotation of the FISH in situation 2**

Conclusion

In this case, a certain amount of force from the FISH and the released line must be applied to the new element to accelerate it. This force retards the acceleration of the FISH. Because of this force, the movement of MAIN Payload, which is connected to the last element, will impact upon the movement of the FISH with regards to both position and rotation.

3. **The new line element has initial velocity which limited at a maximum value.**

The same effects as in the situation 2 in all properties are show up but in the later time. This situation, therefore, is a combination of the first two models. Before the friction limits the acceleration or the maximum line speed is reached, the FISH falls in a near- zero G state. Once the threshold is reach, the acceleration of the FISH is retarded and decreases in a quasi-linear fashion in the absence of gondola perturbations.

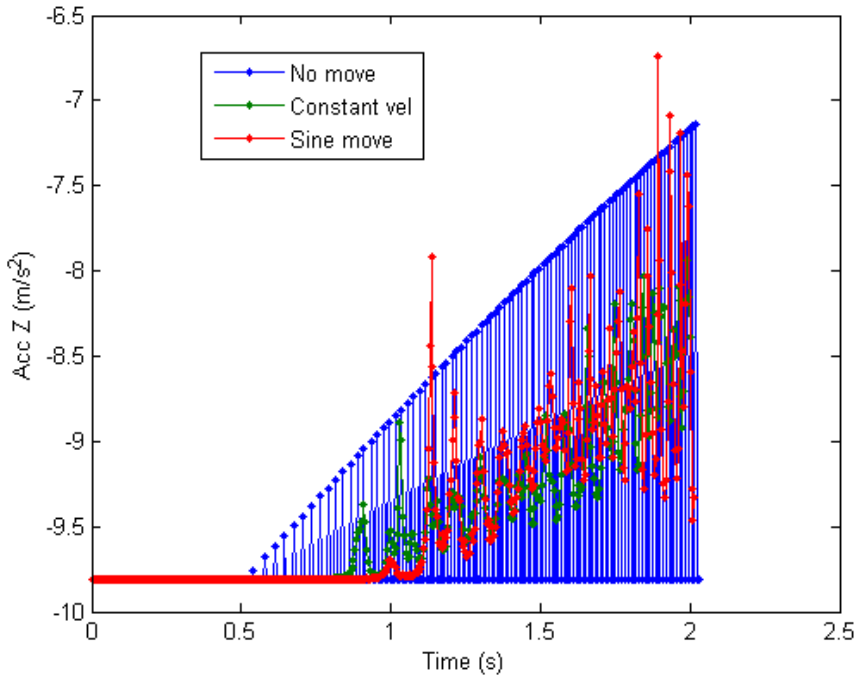



**Figure 3.35 Acceleration of the FISH in Z direction of in situation 3.**

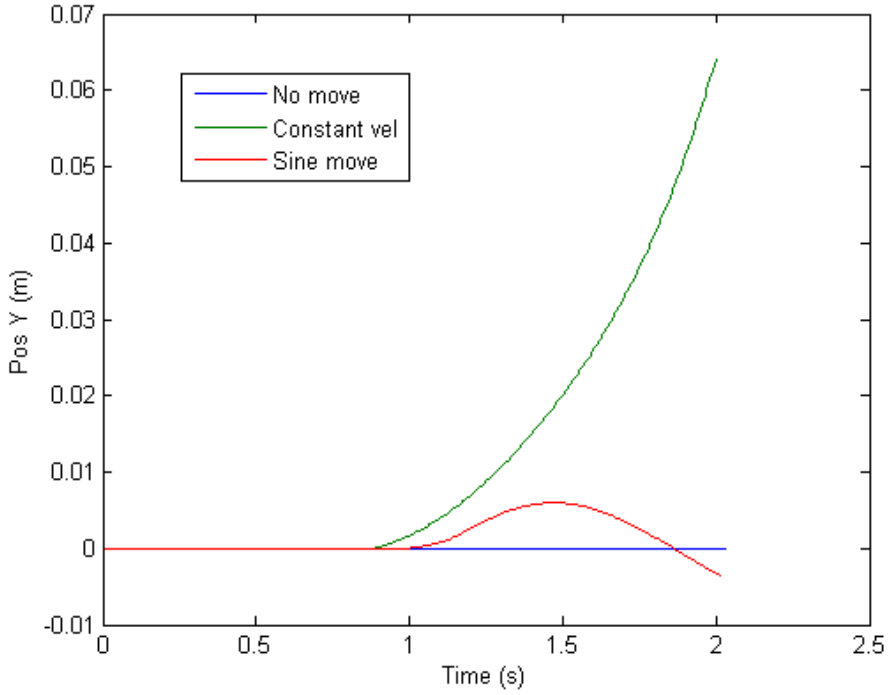



**Figure 3.36 Effect of MAIN Payload movement in position of Y direction in situation 3.**

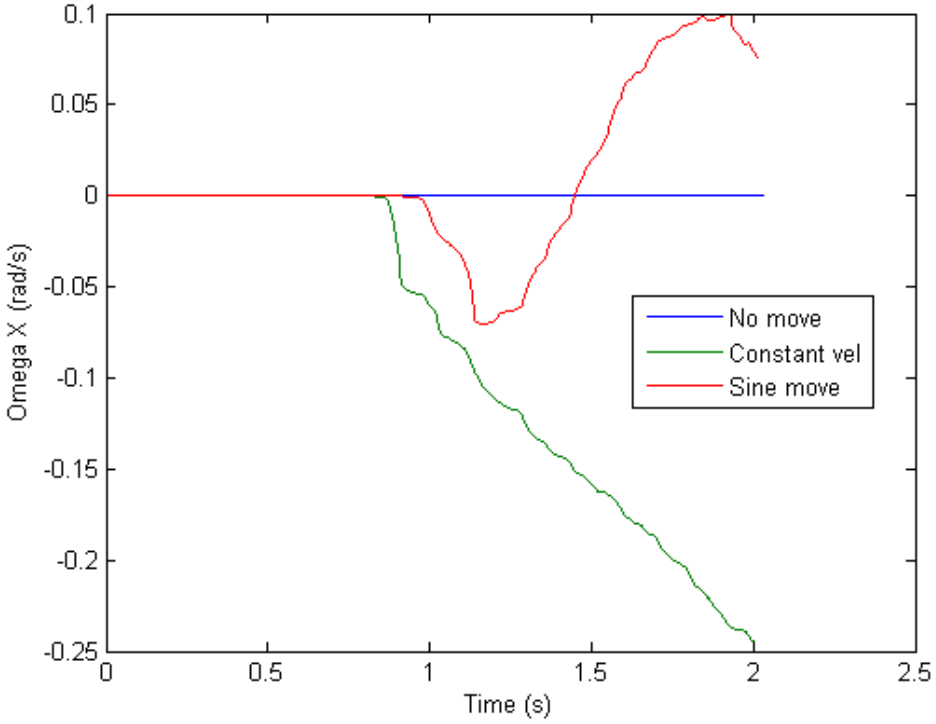



**Figure 3.37 Effect of MAIN Payload movement on rotation of the FISH in situation 3.**

Conclusion

The same effect in situation 2 is caused by the force occur in the acceleration process. In the first period of the free-fall, there is no force required to accelerate the rest of the line. After certain time, the velocity of the FISH and the last line element exceed the limit, the same process in situation 2 is occur which produce the same result later on.

3.10.2.6 Integration time step comparison

In order to study the effect of simulation integration step time on the accuracy of the simulation, a comparison of the results with different time steps is presented here. For this investigation, a sine input with and angular velocity of 4 rad/s and amplitude of 2 m in the y- direction was implemented.

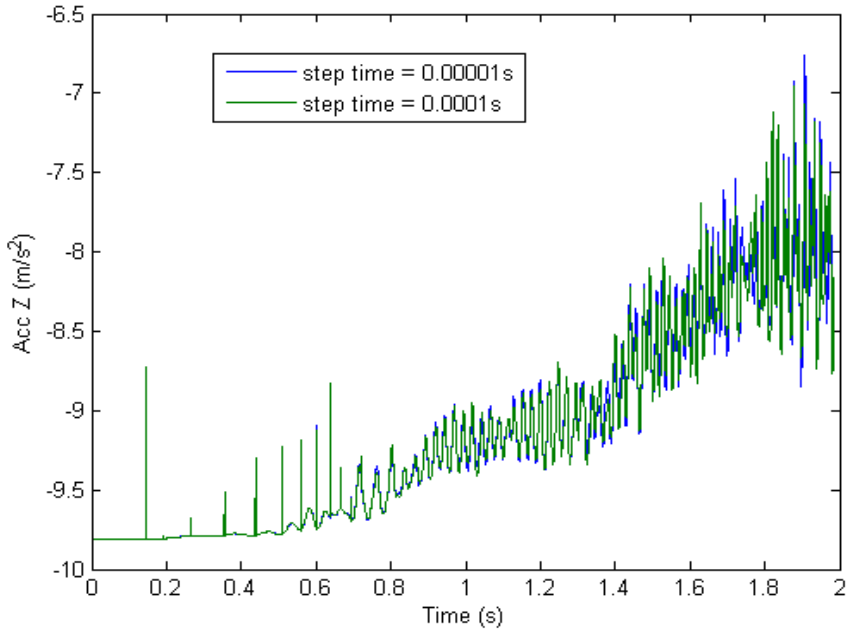



**Figure 3.38 Comparison in size of temp step in simulation on acceleration.**

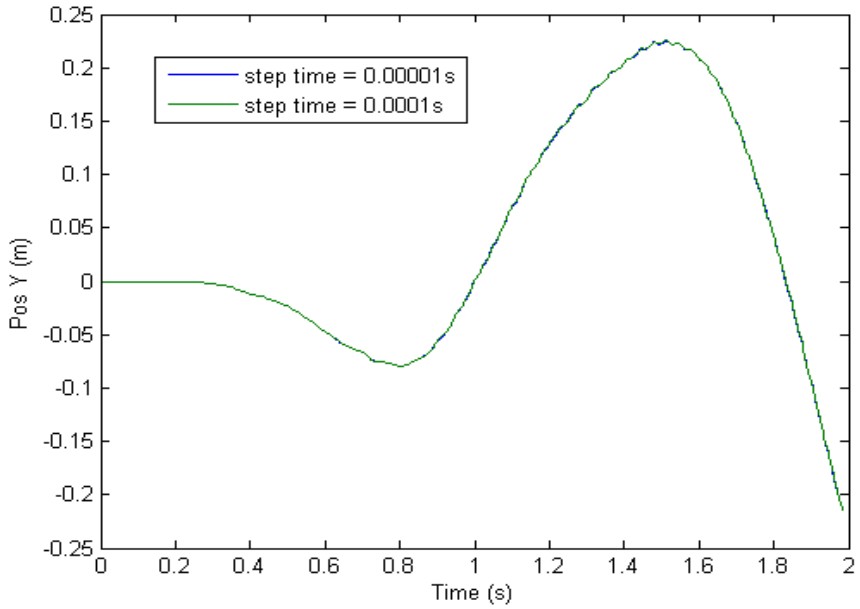



**Figure 3.39 Comparison in size of time step in simulation on position**

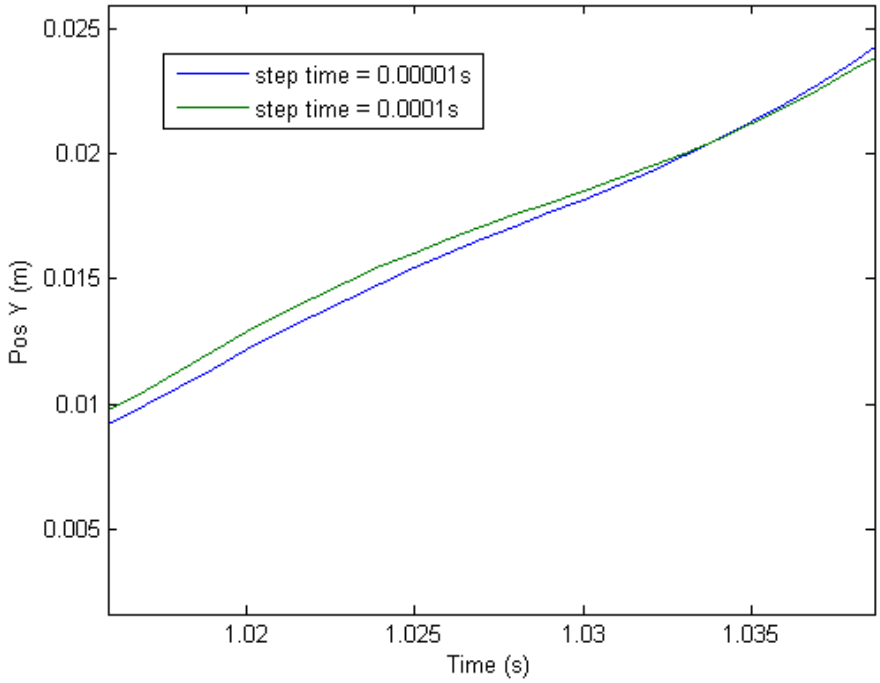



**Figure 3.40 Zoom figure on comparison in size of time step in simulation on acceleration and position**

Conclusion

The simulation results show that over different sizes of step time, the curves depict the same trends and therefore are a reliable indication of system response. This means that the reasonable time step that can provide efficiency in speed is of sufficient accuracy for studying the behaviour of the system. More accurate simulations may be performed by decreasing the time step size.

### 3.10.3 Simulation Summary and Evaluation

The dynamics of the FISH and tether have been modelled during the 'drop phase' of the drop mode of the mission. That is, from the time the FISH is released from the MAIN Payload until just after the braking forces are applied. Therefore the simulation results demonstrate the dynamics of the FISH on the tether under conditions of zero and non- zero line friction in tandem with various arbitrary inputs from gondola motion. Under conditions where the line friction does not cause the line to reach the maximum line-off-reel speed, in the absence of other external disturbances, the FISH shall free-fall. As such, as long as the line is able to fall off the reel below its maximum speed, perturbations from the gondola shall not impact upon the FISH acceleration performance. However, once a maximum line-off-reel speed is reached, then the FISH experiences a non-zero G acceleration. Coupled with horizontal perturbations, this situation involves a drift of the FISH and an offset of the x and y axis from the horizontal plane as well as a low-speed rotation.

In the absence of knowledge about the gondola perturbation levels, the maximum line speed from the reel and the specific frictions of the system, this model only provides an indication of the dynamics of the system. Furthermore, the ability of the ODE physical engine is limited to just rigid body simulation. The atmospheric drag and accurately string simulation shall to be performed by another method. A Flight simulator is under investigation for further study. The preliminary simulation presented here is useful for study of the generalised behaviour of the system but is a coarse model, not taking into account aerodynamic effects or the specific reel behaviour. Nevertheless, the model demonstrated that this system is a feasible method for producing microgravity, if the frictions are minimal and where with associated line speed may be maximised. Once more accurate input values are determined, through further research and testing, this simulation shall be performed again for a more accurate system representation.

# 4 REVIEWS AND TESTS

In this chapter the dates, locations, participants and the main recommendations of the review boards following each review are summarised. To date, the ESW is the only review to have been completed.

## 4.1 Experiment Selection Workshop (ESW)

Date: 3-5 February 2009

Location: ESTEC, Noordwijk, The Netherlands

**Participants:**

a) Experimenters

Katherine BENNELL

Mark FITTOCK

Mikulas JANDAK

David LEAL MARTINEZ

Campbell PEGG

b) Review Board

Representatives of ESA, DLR, SSC

During the ESW, the experiment proposal was presented along with preliminary high level system designs. This included the objectives of the experiment, background information, team structure, technical concepts, interfaces, data collection, safety issues, financial and scientific supports as well as the outreach plan. This presentation may be found in Appendix A.10.

**Recommendations of the Review-Board:**

That the reel.SMRT team must:

1. Provide a detailed risk analysis and design of a safety system
2. Be very careful with planning and ensure sufficient time to implement the safety system.
3. Provide more details on your braking system and the related frictions
4. Give more details on how the system will be tested
5. Assess the drift of the FISH during a drop and its consequences on the whole system and the measurement accuracy.

**Response to the Recommendations of the Review-Board:**

1. Refer to Section 5.5 and individual subsystem designs. Particularly, mechanical risks are addressed in Section 3.5.3 and Section 3.5.5.1.
2. Refer to Section 5.1.
3. Refer to Section 3.5.2
4. Refer to Section 4.5
5. Refer to Section 3.10.

## 4.2 Preliminary Design Review - PDR

Date: 22- 27 March 2009

Location: Oberfaffenhoffen, Germany

**Participants:**

| a) Experimenters | b) Review Board |
|---|---|
| Katherine BENNELL | Unknown |
| Mikulas JANDAK | |
| David LEAL MARTINEZ | |
| Mikael PERSSON | |
| Jan SPEIDEL | |

**Recommendations of the PDR-Board:**

Not Yet Applicable

## 4.3 Critical Design Review - CDR

Date: May/June 2008

Location: TBD (To be decided)

**Participants:**

a) TBD

b) Review Board

**Recommendations of the PDR-Board:**

Not Yet Applicable

## 4.4 Experiment Acceptance Review - EAR

Not Yet Applicable

## 4.5 Test plan

Due to the complex and highly mechanical nature of the project, the testing of reel.SMRT will be rigorous. Flight in the stratosphere necessitates validation both of components, interfaces and system performance in thermal and low pressure environments. In this section, the tests and test plans for each subsystem are presented. Further information about each test, including the test objectives, procedure summary, location, conditions and required resources may be found in the Appendix M.4.

Testing facilities utilised in the test plan include the thermal and vacuum chambers at IRF, which have been secured for this project. Furthermore, there is the possibility to fly on EXUS balloons to validate the operation and performance of segments of the payload, if the ground tests are insufficient to model system performance and interfaces. The team has also been in consultation with the Delta Utec tether company, who have offered their time, expertise and equipment for a system test (see Appendix M.5). However, at 3000 euro, this test is currently beyond the team budget and so will not be able to be conducted in the absence of a sponsor. Such a test would measure the tension and oscillations in the line that would enable a better prediction of the reel-system performance. Nonetheless, the system will be tested by dropping the payload off a drop tower or down a mine shaft. This, however, is not a true environmental test. Rigorous testing of each component and interface in the thermal and vacuum chambers should, however, verify the performance under the adverse stratospheric conditions.

### 4.5.1 Mechanical Subsystem Tests and Test Plan

As shown in Figure 4.1, the mechanical tests are planned from the beginning of April to the end of June, which should leave enough time for contingencies. The testing program will first involve the testing of the strength of the central components such as the reel, the line, the line interface, the braking strength, and line guide. Then, as components of the prototype are built, they will be tested also. When the FISH is built, the insulation and interface to the line will be verified. Then, as the mechanisms of the MAIN Payload are built, they will be tested for strength, reliability, and functionality. Most of these tests will be performed in the month of May as the prototype of the MAIN Payload is expected to take some time to be machined, purchased, and assembled. Finally, once the entire system is assembled, advanced tests will be performed in the FISH payload and its behaviour under free-fall conditions in the stratosphere. Additionally, some tests will be done on the aerodynamics of the FISH if time and resources allow. For more details on the specifications of the tests, refer to Appendix M.4 for a complete table of the test cases.

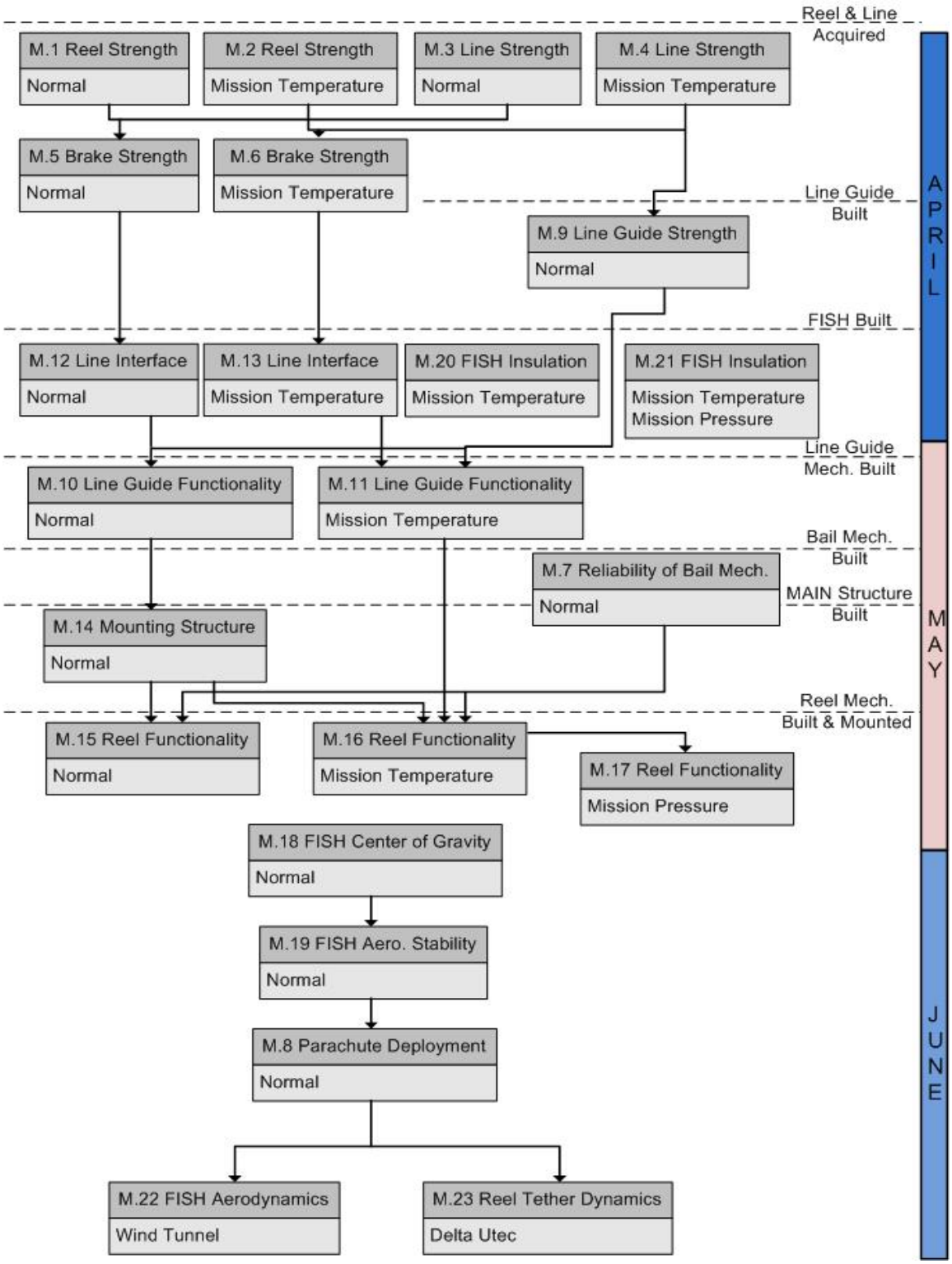



**Figure 4.1 Mechanical Test Timeline.**

### 4.5.2 Electrical Subsystem Tests and Test Plan

Figure 4.2 shows different tests which are to be performed after the design. The bulk of the tests are to be performed in May after the PCB is populated. The figure shows dependencies between different tests. The most fundamental tests are to be done at the beginning – all the basic tests. The more complex tests are to follow. Some of these tests are conditional for particular hardware to be used in the final design. For example the magnetic compass test may be replaced by another test which is to calibrate the alignment between fish and the main payload. Nonetheless, almost all of these tests are to be performed. Figure 4.3 shows tests with respect to time and also to other subsystems. These tests although show separately may be combined with others in order to use more effectively the recourses (pressure chamber, temperature chamber).

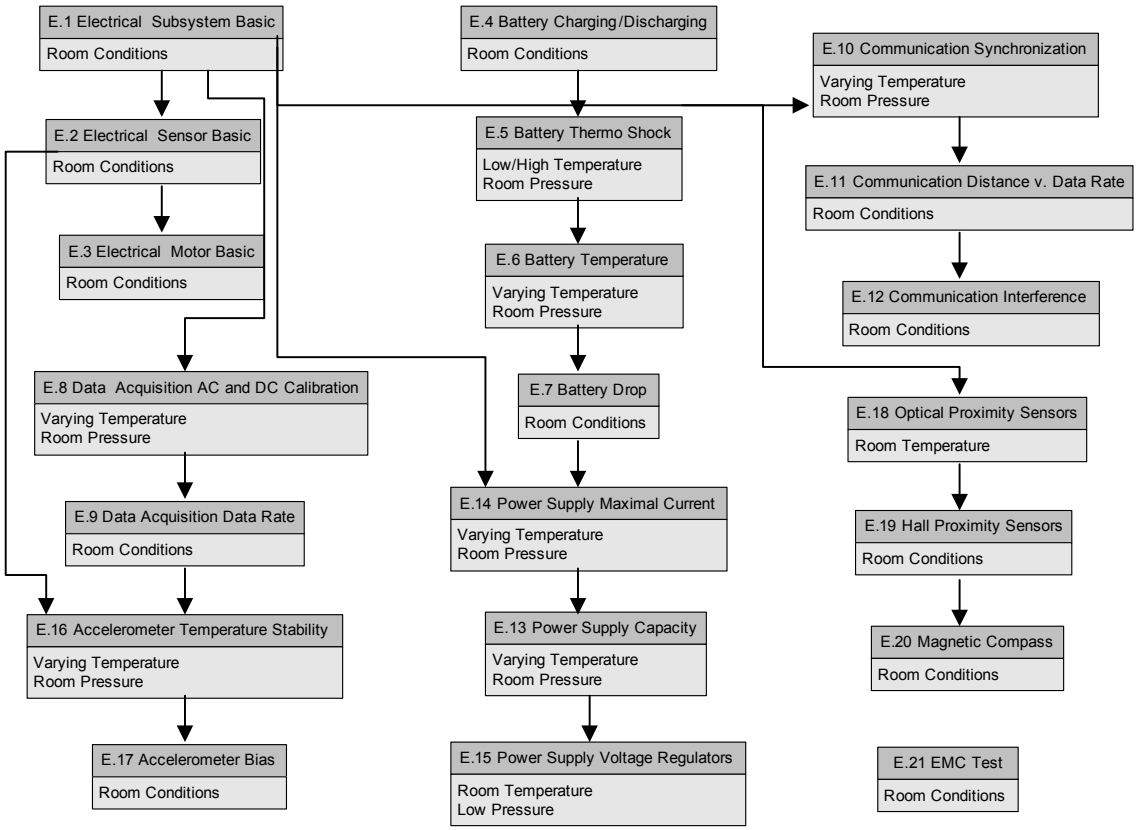



**Figure 4.2 Electrical Tests**

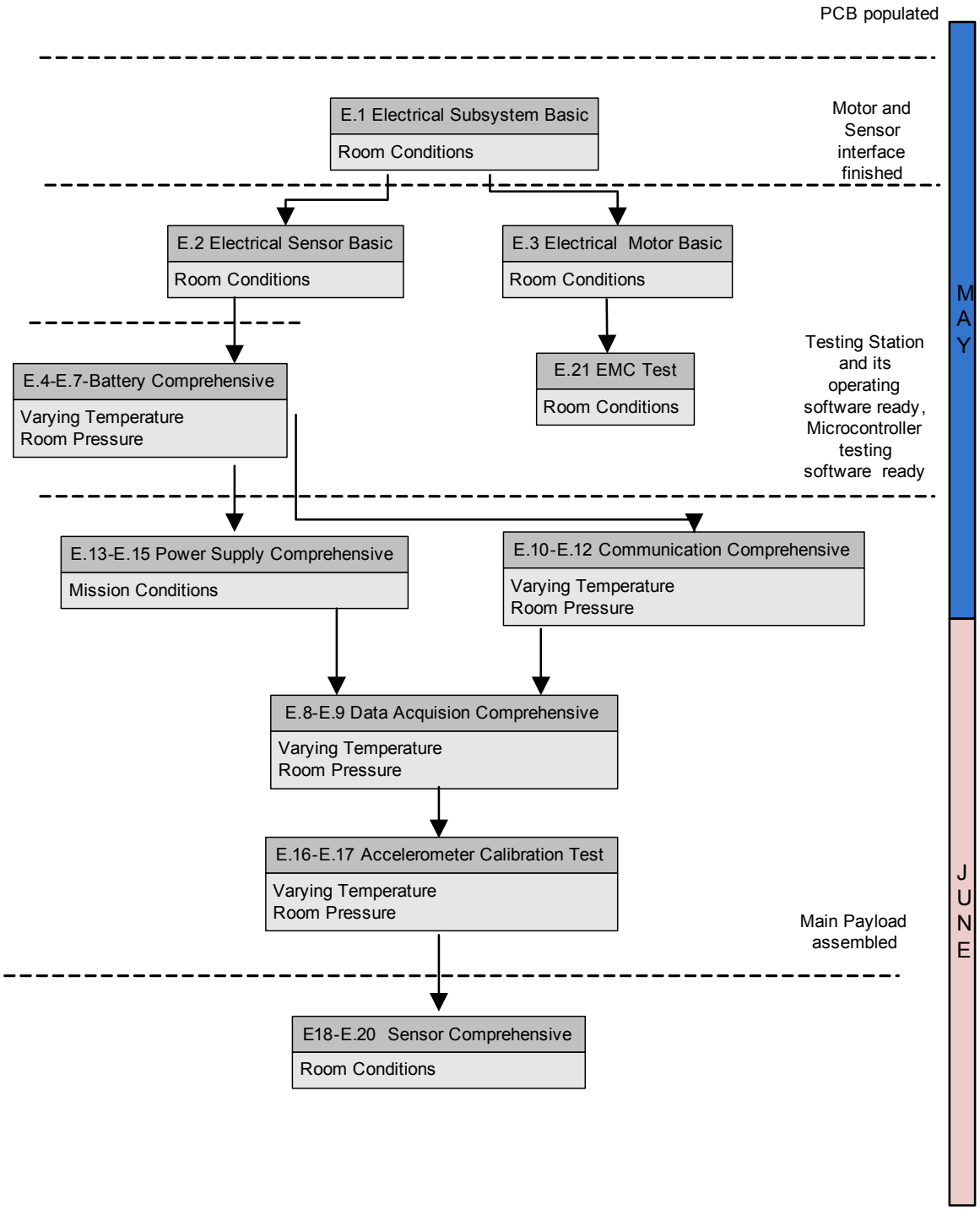
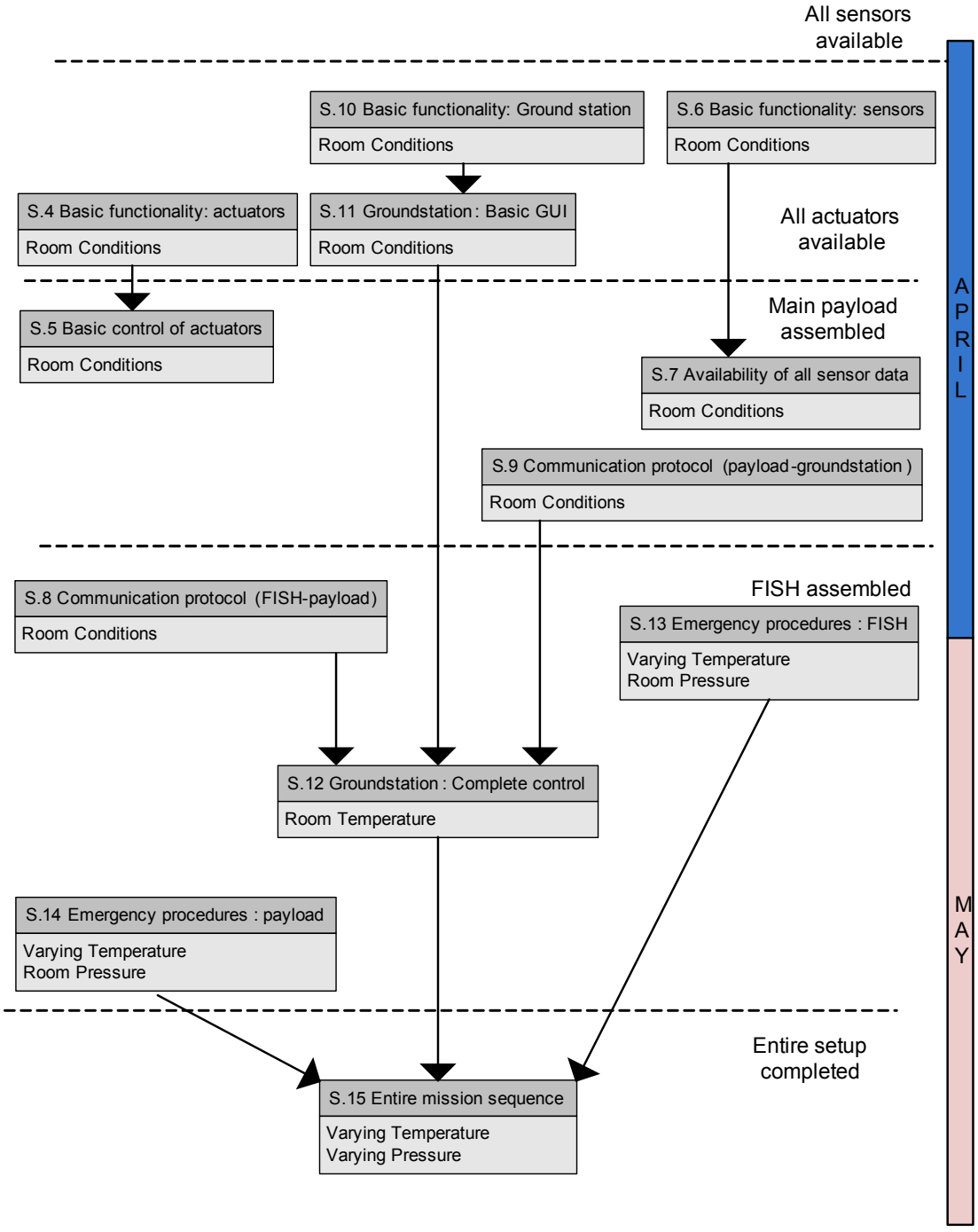



**Figure 4.3 Electrical Tests 2**

### 4.5.3 Software Subsystem Tests and Test Plan

During the development of the software it is possible to test three subparts independently. These parts are Ground station, sensors, and actuators. Also it is not necessary to do a lot of testing in vacuum chambers or in varying temperature. Only when it comes to moving parts (actuators) and a test of the whole setup in mission conditions is necessary.



# 5 PROJECT PLANNING

## 5.1 WBS – Work Breakdown Structure

The reel.SMRT Project team is comprised of nine students from the 'Erasmus Mundus Joint European Master in Space Science and Technology', or 'Spacemaster'. There are three Round 3 members, in their second year of the program and six Round 4 members, in their first year of the program and currently studying at LTU in Kiruna, Sweden. More information about the taskings and backgrounds of each member are presented in Section 1.5.

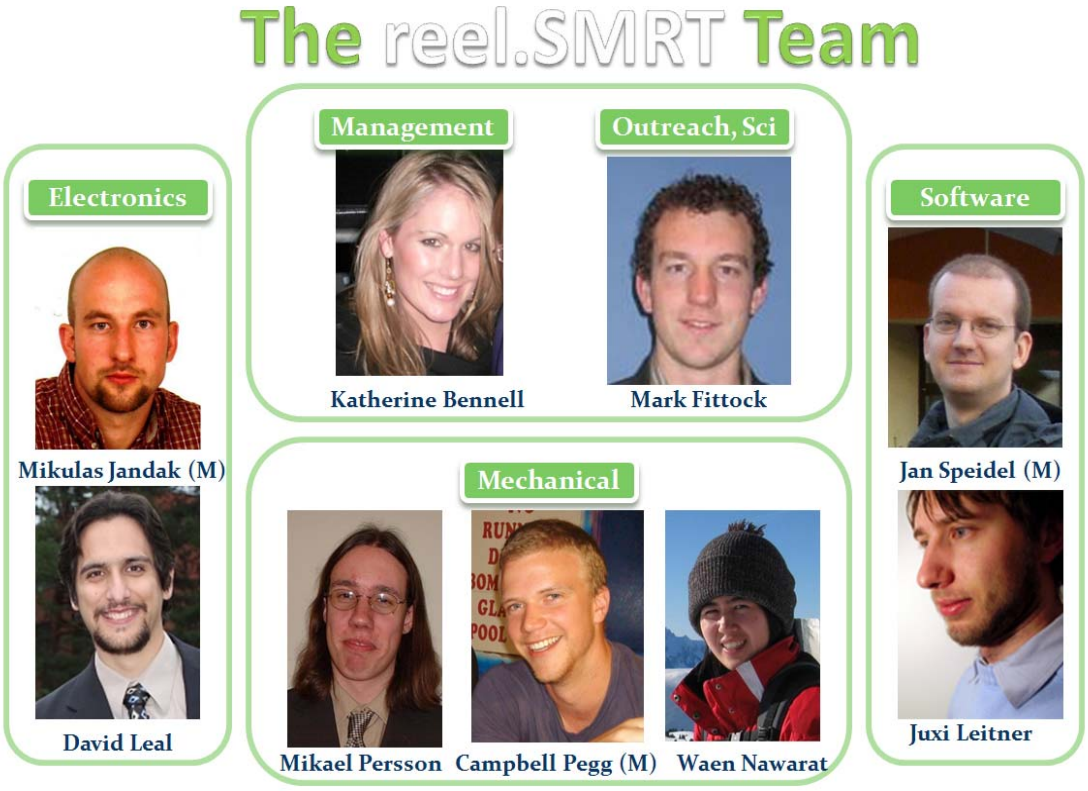



**Figure 5.1 The reel.SMRT team structure**

Each member of the reel.SMRT team is expected to do equal amounts of work to achieve the best outcome for the project. The workload required is dictated by task allocation and thus is outcome driven (tasks achieved) rather than time driven (hours per week). The detailed taskings for each member were established immediately following the ESW and are monitored both by the Subsystem Managers and the Project Manager. Within each subsystem, the subsystem manager is responsible to the Project Manager for the implementation of their tasks. This means that the Subsystem Managers delegate tasks within their subsystem and ensure their timely completion as well as keep their overseas counterparts up to date. The team is structured so that the Subsystem Managers

and the Project Manager are all located in Kiruna for ease of communication and control. The interface definition between each subsystem and thus subsystem responsibilities may be obtained from the Section 3.4.2.. The team and the groupings are displayed in Figure 5.1.

## 5.2 Management

### 5.2.1 Project Planning Methodology

Unique management challenges are present in this project. The team, being composed of nine members currently spread across four separate countries, all with a variety of backgrounds and not previously well acquainted with one another, posed potentially significant barriers to communication and collaboration. To meet such challenges, a comprehensive project management plan has been implemented with a dedicated member as the project manager. This enables more thorough time planning and interface supervision, in addition to greater command and control capability over the team. At the commencement of the project it was made clear to each member their individual responsibilities as a group member for this project, the management structure and the level of workload involved. An email list, a file sharing website and a milestone/task page on the 'basecamp' website was established through which communication of all project information has been made. The DLR sharepoint site has also been established the key file sharing site for the team, enabling more efficient compilation of design and administrative documentation. This ensures that all members of the team are aware of the developments within each subsystem design and may access and add to these documents in an efficient manner.

Bi-weekly meetings occur for the six members present in Kiruna, with additional weekly meetings held with the entire team present over the Skype conference call system. During these meetings, each member presents the work since the last meeting and in doing so the team members push each other to work harder and maintain the pace of the design progress.

The initial taskings to the subsystems were as follows, in order of priority: subsystem task breakdowns and timelines, subsystem requirements and initial budgets, inter-subsystem interface definitions, initial design, risk analysis, test plan and then the more advanced preliminary design analysis. Such staggered taskings in the five weeks to PDR enabled more effective work planning and workload distribution over this period.

#### 5.2.1.1 Interface Definition

Management involves responsibility for system integration, that is, the collaboration of all the subsystems to produce the final design product. Initially

high level requirements and constraints of the project were developed, including budgets to guide the development of each subsystem. This presented a 'top down' approach to the satellite design.

Integration in the design phase involved setting requirements, defining subsystem interfaces, whilst integration in the construction phase shall require thorough testing of all interfaces. For this design phase B, each subsystem was tasked with setting strict requirements that defined the constraints on their designs from other subsystems. An Interface Control Document was established, where subsystems together defined their interfaces and the responsibilities of members involved in these interfaces. Consequently, the onus was placed on each subsystem to ensure that the performance of their particular subsystem shall be in compliance with the functional and technical requirements.

#### 5.2.1.2 Design Budget Establishment

A key part of the preliminary design process was the establishment of the budgets. Budget development was an iterative process and relied upon input from all subsystems such that appropriate division of the available limited resources could be obtained. To begin with, the total budget for each of the five main resources was identified: power, data, volume, mass and cost. Also an important factor was to identify which of these budgets could be modified and which were fixed without possibility for deviation, based on the mission requirements and constraints.
Once the preliminary budgets were initialised, each subsystem researched preliminary design options that could be used to satisfy the functional, technical and operations requirements, accounting for the resources available. In the bi-weekly coordination meetings, the team compared and negotiated the resources that each subsystem believed they required from teach budget. To keep track of the compromises between requested budget resources and allocated budget resources, a confidence level for each budget allocation, determined entirely by the affected subsystem, was then attached. Once sufficient research and discussion were undertaken to have confidence levels at 60% or greater, the final budgets were set. This process is depicted in Figure 5.2 Flowchart of the process and iterations of the Budget development for reel.SMRT.

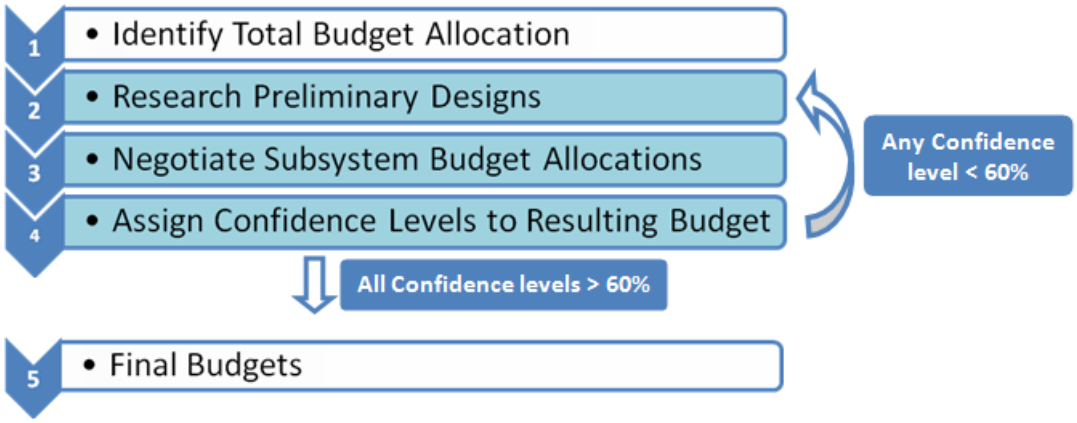



**Figure 5.2 Flowchart of the process and iterations of the Budget development for reel.SMRT.**

In this document, the summarised preliminary budgets for mass, volume, power and data are presented in Section 3.1. More detailed budgets may be found in the Appendix A2, A3, A.4, A.5.

## 5.3 Resource estimation

Estimation of the resources for the reel.SMRT project necessitates and investigation into a number of factors. These include, in addition to the individual team members: finances, time, components, access to facilities for testing and construction as well as academic and financial support. In this section, each of these factors shall be addressed.

### 5.3.1 Mission Finance Budget

The reel.SMRT project finance budget depends on the size, complexity and scheduling of the project. It also is a function of risk mitigation levels, component quality and proficiency of team members in locating the optimal products. The project budget is capped by the individual members willingness and ability to pay over a certain threshold level for the project, which may vary for each member but must be set to an equal contribution across all members. Within this framework the aim was to minimise all costs, where possible, without compromising the quality of the design or the ability to meet the objectives.

The prediction of the total budget was a complex process critical to determining the quality and feasibility of the design, and as such was also critical to the development process.

The project budget was based on information gathered and recorded systematically to allow for accurate estimates of cost. The cost estimating method employed was that of ‘Detailed Bottom-up Estimating’. This involved identification and specification of costs from the lower level elements that make up the system (34). This concerned the establishment of subsystem budgets that were integrated into an overall system budget. The project budget was also further divided into

cost groups within each subsystem: components, tests and conference travel costs. Any component that had the possibility for sponsorship was also identified and labelled to be addressed by the member responsible for outreach and the Project Manager.

The cost estimation contributed to key design decisions, such as the quality of components. For example, ideally the mission would produce more accurate results with a high quality accelerometer, which may enable the performance to be measured in relation to drop towers. However, the cost of this component was excessive and prohibitive to its implementation. As such, sponsorship must be established before this component can be included in the design, and the minimum cost accelerometer able to meet the mission requirements was implemented. Similarly, the total system test as arranged with the Delta Utec tether company involves a fee of 3000 euros. This cost is beyond our budget and unless funding for this venture may be secured, this test shall not proceed.

Such dependencies on funding incur delay in the finalisation of designs and the schematics, as well as ordering lag time. To minimise this and to reduce the total budget, sponsors and supporting organisations have been approached from the commencement of the project to ensure maintenance of design momentum and more accurate cost estimation. For some components, negotiations are currently underway. For instance, 50% price reductions on the reel and line components has been guaranteed, and the price is likely to be further reduced.

To facilitate sufficient reserves for subsystems to purchase the necessary components, a joint bank account for the team has been established. By each team member transferring in their contribution, pre-approved purchases may be made in a timely manner.

The preliminary budget for the reel.SMRT Project is summarised and listed in Table 5.1. More detailed subsystem cost budgets are listed in the Appendix A.3.

| Subsystem | Actual Price (Euro) |
|---|---|
| | |
| **Mechanical** | |
| FISH | 490 |
| MAIN | 1434 |
| Total | 1924 |
| | |
| **Electrical** | |
| MAIN | 840 |
| FISH | 1193 |
| Total | 2033 |
| | |
| **Software Subsystem** | 20 |
| **Outreach** | 35 |
| **Management** | 555 |
| | |
| **Total** | **7534** |

**Table 5.1 Mission Financial Budget (summary)**

### 5.3.2 Time schedule of the experiment preparation

The approach taken to the time schedule of the mission and experiment preparation is that of working hard from the beginning, with the aim to achieve that ever-elusive 'flat' effort versus time curve over the project phases. This is particularly necessary due to the many validation tests required for the mission. If all tests are on schedule and produce favourable results, then the ideal situation of the testing phase being complete with a flight ready model at the beginning of July shall occur. However, due to the many components that must be ordered in and the possibility of the necessity for re-designs following unfavourable tests, or unforeseen member time availability, a 'buffer' period has been set from the end of June until September. This time comprises the 'summer break' for the members of this project and so any additional overflow work may be completed in this period, if required.

The mission phases and milestones are listed as follows:

**Phase A: Feasibility Phase**
- October 2008 Proposal Submission
- February 2009 Experiment Selection Workshop

**Phase B: Preliminary Design Study Phase**

**Phase C: Detailed Definition Phase**
- March 15 PDR Due (ESA)
- March 22-28 PDR Workshop and Presentation (ESA)
- April 1-7 PDR deadline (IRV)

**Phase D: Production and Qualification Phase**
- June 2009 CDR (ESA and IRV)

***Begin 'Buffer' Period***
- August 2009 MTR (ESA)
- TBD MTR
- TBD Flight Readiness Review

***End 'Buffer' Period***
- September 2009 Delivery of Experiment Flight Hardware (ESA)

**Phase E: Launch and Operation**
- September 2009 Final Report (IRV)
- September 2009 EAR (ESA)
- 2 October Launch Campaign (ESA)

**Phase F: Post flight analysis and Final Report**
- 8 January 2009 Experiment Report (ESA)

A Gantt Chart has been implemented for monitoring the progress of the project because it enables a direct correlation of tasks with the duration of time, milestone and critical task amelioration, flexible time units for future tasks, and a visual representation for quick assessments of the project's progress. This is particularly important in this project necessitates fast development in the initial stages, and shall continue to require a maintenance of momentum over the coming months. Each subsystem has set their own timeline and shall continue to update it as the project progresses, with the Project Manager overseeing the progress relative to the chart. By each subsystem setting their own tasks, they are aware of deadlines and push themselves to achieve their tasks. The current Gantt chart is appended to this document in Appendix A.6.

### 5.3.3 Ordering of components

Ordering of components shall commence immediately following the PDR. This is facilitated by the fact that some key suppliers have already agreed to provide components at a discount; others are currently in negotiations with the team.

### 5.3.4 Facilities for construction and testing

A number of resources are available at hand to the members of the team. These include but are not limited to:

- Electrical Components from IRV and TKK
- Mechanical Structure Materials from IRV
- Electrical Laboratory and Workshop at IRV
- Mechanical Workshop at IRV
- Manufacturing from IRF
- Library (including past EXUS and BEXUS materials) at IRF
- Electrical Workshop at TKK

### 5.3.5 Sponsorship

A sponsorship template letter has been written for the project, and will be used for all sponsorship applications (shown in Appendix A.9). A two page system summary and brochure has also been drafted to attach to this letter for companies who may be interested in more background details of the project. The sponsorship letter itself has already been sent out to the following companies: Fishing Australia Magazine (general support), Daiwa (fishing reel), Platypus (tether-line), Honeywell (accelerometers), Groschopp (DC Motors), Airsafe (Parachute) and NXP (Evaluation board). Current confirmed sponsorship is from LTU. Current confirmed sponsorship includes a 50% reduction to both the fishing reel and line from the Fishing Australia Magazine. Additionally, the gyroscopes for both the FISH and the MAIN Payload have been obtained at no cost through a fellow Spacemaster student and Prof. Reinhard Gerndt from University of Applied Sciences, Wolfenbüttel, respectively.

### 5.3.6 Supporting organisations

In addition to the facilitators of the BEXUS program, reel.SMRT is supported in Helsinki by TKK and in Kiruna by IRV. The physical components of this support are listed above as resources. This also allows access to professionals many of whom have prior experience with space quality hardware and project expertise. Additionally, LTU has provided funding support to the value of 5000sek for components ordered through Swedish suppliers.

## 5.4 Hardware/Software Development and Production

### 5.4.1 Mechanical hardware development

The very first step is to purchase and obtain the reel and line to be able to finalize the design of the MAIN and FISH. Then, machine drawings will be built and time will be booked at the machine shops of IRF and IRV. The manufacturers of the off-the-shelf components will be ordered. The priority will be given to the assembly of the mechanisms of the MAIN Payload in parallel to the construction of the FISH. As the mechanical parts are completed, the test planning will be performed as described in Section 4.5.1. Design iterations might occur during the above phases and are taken into account through contingency planning as part of the testing phase.

### 5.4.2 Electrical Hardware Development

When building the electrical hardware the most important factor is to design the PCB and start its construction. The time taken for the PCB to be constructed will limit the rest of the building phase. The manufacturing of the PCB will take approximately 1-2 weeks to be made and returned to the reel.SMRT location. The PCB will be populated no later than the last week in April such that testing may begin in earnest at the beginning of May.

The population of all PCBs is to be done in IRF Electronic lab, where proper equipment for soldering SMD components is available. Another option is to populate one of the PCB at TKK in Helsinki and other one in IRF because of the separation of the two electrical personnel. This will reduce the work load for both of the electrical members.

Before the PCBs are populated the bulk of the electronic is to be ordered. All of the components are to be purchased most of them at Farnell.

Significant changes to hardware or software are presented in the bi-weekly team meetings. When the change directly affects an interface with another subsystem, both subsystems arrange to discuss the design and present their solution together. Changes are recorded in the component lists or design documentation on the DLR sharepoint site.

### 5.4.3 Software Development

The software for both microcontrollers is developed using the evaluation board MCB2300 from Keil. It allows easy testing and troubleshooting of software parts in a very early stage of the software development part. For programming the integrated development environment (IDE) WinARM (35) is used. It acts as a graphical user interface of the popular gnu-gcc compiler (36). As long as the sensors and actuators are not available for programming, the development of the software is carried out using the evaluation board again. Besides the WinARM IDE and the gnu-gcc compiler the real-time operating system FreeRTOS (37) is used. Most of the peripherals of the microcontroller are supported by FreeRTOS. For the Ethernet stack however the free software suite µIP is used (38). All programming will be done on Microsoft Windows based computers. The microcontroller will be programmed using either the ISP interface or the JTAG connector. For testing of the software the unit testing procedure will be used. On top of that each control algorithm will be tested according to the test graph in Section 4.5.3..

## 5.5 Risk management

The risk management methodology involved each subsystem filling out a risk matrix to identify the critical risks. These risks were further divided into implementation risks and mission risks.

This involved establishment of potential failure scenarios and their severity and probability for each mode of the mission. A value of 5 represented the greatest severity and highest probability for each case. Any risk involving safety to personnel incurred a severity value of 4 or 5. The critical risks were identified from this matrix, and are presented in this chapter. For each critical risk, an ID number, name, description, severity and probability and total risk and actions taken to minimise the probability and severity of the scenario are described. The reaction to this risk and the recovery method are also displayed. The complete in-depth risk analysis is shown in Appendix A.1

### 5.5.1 Mechanical Subsystem Risk Management

#### 5.5.1.1 Mechanical Implementation Risks

For the implementation phase of the mechanical design, the following major risks have been identified:

| | |
|---|---|
| **ID** | I – M 03 |
| **Name** | Destruction of mechanical parts |
| **Description** | Parts are destroyed during implementation or testing of the experiment. |
| **Consequences** | Objectives cannot be achieved |
| **Severity** | 2 |
| **Probability** | 5 |
| **Total Risk** | 10 |
| **Prevention** | Have spare parts and excess material |
| **Reaction** | Replace faulty parts or machine replacement parts from spare material |
| **Recovery** | Full recovery after test |

**5.2 Risk ID I-M03.**

#### 5.5.1.2 Mechanical Mission Risks

During the operation of the mission the following major risks have been assessed.

| | |
|---|---|
| **ID** | M – M 01 |
| **Name** | Loss of Reel Drive Motor during the Brake Phase |
| **Description** | When the FISH is being decelerated the reel drive motor is used to flip the bail to catch the line and transfer the force through the bail and the brake, possibly transferring strong torques through the drive |
| **Consequences** | The FISH will continuously fall until the line runs out |
| **Severity** | 5 |
| **Probability** | 3 |
| **Total Risk** | 15 |
| **Prevention** | Testing of the system at the mission temperatures will be conducted before launch |
| **Reaction** | Use of a backup lock mechanism to stop the line (line guide) |
| **Recovery** | Line guide will be used to reel the FISH back up and the FISH will be housed safely in the SMRT payload |

**5.3 Risk ID M-M04.**

| | |
|---|---|
| **ID** | M – M 05 |
| **Name** | Loss of Line Guide Drive during all phases |
| **Description** | If the brake fails then the line guide will be used. The line guide will turn and stop the line and reel it back up |
| **Consequences** | The FISH will continuously fall until the line runs out |
| **Severity** | 5 |
| **Probability** | 2 |
| **Total Risk** | 10 |
| **Prevention** | Testing the line guide to make sure it works |
| **Reaction** | The last winding of the line will be glued to the barrel of the reel which will rip off and slow the FISH to a stop |
| **Recovery** | The FISH will be reeled back by the reel, or left hanging if the reel drive is also broken and then collected with the balloon |

**5.4 Risk ID M-M05.**

| | |
|---|---|
| **ID** | M – M 06 |
| **Name** | Failure of Line Guide during all phases |
| **Description** | If the line guide is being used then another part has already failed. The line guide will use direct friction with the line to stop it and then reel it back up |
| **Consequences** | The FISH will continuously fall until the line runs out |
| **Severity** | 5 |
| **Probability** | 2 |
| **Total Risk** | 10 |
| **Prevention** | Testing the line guide operation. |
| **Reaction** | A guard below the line guide to catch the guide if it falls. Let the FISH hang in the position that is has fallen to from the balloon |
| **Recovery** | The mission is over and the FISH will be collected with the balloon |

**5.5 Risk ID M-M06.**

| | |
|---|---|
| **ID** | M – M 08 |
| **Name** | Failure of Line or Interfaces of line during Braking Phase |
| **Description** | The line or line interfaces could break or come undone during any phase of the mission |
| **Consequences** | The FISH will fall to the ground at terminal velocity |
| **Severity** | 5 |
| **Probability** | 2 |
| **Total Risk** | 15 |
| **Prevention** | Test the strength of this line at the mission temperature |
| **Reaction** | The parachute will be deployed and the FISH velocity will |

| | |
|---|---|
| | be reduced to a safe speed |
| **Recovery** | The FISH will retrieved if possible, otherwise will remain where it lands. |

**5.6 Risk ID M-M08.**

| | |
|---|---|
| **ID** | M – M 09 |
| **Name** | Failure of Line or Interfaces of line during the Line Guide use |
| **Description** | The line guide is to be used if the reel fails. The friction of this line guide against the reel might cause it to break |
| **Consequences** | The FISH will fall to the ground at terminal velocity |
| **Severity** | 5 |
| **Probability** | 2 |
| **Total Risk** | 10 |
| **Prevention** | The line frictions will be tested at the correct temperature |
| **Reaction** | The parachute will be deployed and the FISH velocity will be reduced to a safe speed |
| **Recovery** | The FISH will be retrieved if possible, otherwise will remain where it lands. |

**5.7 Risk ID M-M09.**

Thus the areas that have a high severity rating if fails, are the break, line, line guide and catch mechanism. The chance of these mechanisms failing is relatively low and many precautionary actions have been implemented to stop a complete failure. Majority of high severity situations have been reduced to via implementation of the line guide which is able to lock of the line if an irregular falling occurs. This line guide will stop all situations of failure that occurs above the line guide. Also a wire mesh has been placed below the line guide and the reel to stop any mechanical failures falling to the ground. The only major risk that has not been mentioned is the potential for the line or interfaces to brake and hence cause the FISH to fall to the ground. To reduce the potential of this happening is by implementing the strongest fishing line that is on the market which is able lift an approximately 90 kg's. Also a parachute has been placed inside the FISH to ensure if all else fails then capsule will slowly descend. Thus for all possible mechanical failures the probability for a safety risk to occur is highly improbable.

### 5.5.2 Electrical Subsystem Risk Management

5.5.2.1 Electrical Implementation Risks FISH

For the implementation phase of the electronics, the following risks have been identified:

| | |
|---|---|
| **ID** | I - E03 |
| **Name** | Destruction of PCB |
| **Description** | PCB is destroyed or heavily damaged |
| **Consequences** | Repairs or new PCB needed |
| **Severity** | 4 |
| **Probability** | 3 |
| **Total Risk** | 12 |
| **Prevention** | |
| **Reaction** | Try to repair the PCB board or order a new one |
| **Recovery** | Recovery is possible |

**5.8 Risk ID I-E03.**

5.5.2.2 Electrical In-Flight Risks MAIN

For the mission phase, the following risks have been identified about the FISH payload in the Electrical Subsystem:

| | |
|---|---|
| **ID** | M - E01 (I - Implementation, M – Mission)) |
| **Name** | Destruction of a critical component |
| **Description** | Critical component (microcontroller, AD converter, analogue circuitry, voltage reference, precise accelerometer, wiring between PCB's and PCB's itself) stops working during the mission. |
| **Consequences** | Objectives cannot be achieved |
| **Severity** | 5 |
| **Probability** | 3 |
| **Total Risk** | 15 |
| **Prevention** | Using high quality components, proper testing |
| **Reaction** | Notifying ground station |
| **Recovery** | Recovery not possible |

**5.9 Risk ID M-E01.**

| | |
|---|---|
| **ID** | M - E03 |
| **Name** | Malfunction of ONE battery set |
| **Description** | One battery pack stops working, gets shorted |
| **Consequences** | Limited operational time or/and deterioration in quality of the acquired data |
| **Severity** | 3 |
| **Probability** | 3 |
| **Total Risk** | 9 |
| **Prevention** | Implementing active (current monitors) and passive (fuses) protection circuits, vigorous testing of power supply |
| **Reaction** | Notifying ground station, using power safe down mode |
| **Recovery** | Fully recovery not possible |

**5.10 Risk ID M-E03.**

| | |
|---|---|
| **ID** | M - E08 |
| **Name** | Malfunction of memory |
| **Description** | Memory cannot be used for storing data. |
| **Consequences** | Previous data may be lost if not successfully sent to the main payload. |
| **Severity** | 4 |
| **Probability** | 1 |
| **Total Risk** | 4 |
| **Prevention** | Using high quality components, proper testing, |
| **Reaction** | Monitor Data flow into main Payload, use microprocessor internal memory, restart memory?? |
| **Recovery** | Recovery may be possible during the mission |

**5.11 Risk ID M-E08.**

| | |
|---|---|
| **ID** | M - E09 |
| **Name** | Malfunction of memory and communication link |
| **Description** | Memory cannot be used for storing data, communication link stops working. |
| **Consequences** | Previous data may be lost if not successfully sent to the main payload. Data only for circa 3 drops could be stored in the main microcontroller memory. |
| **Severity** | 5 |
| **Probability** | 1 |
| **Total Risk** | 5 |
| **Prevention** | |
| **Reaction** | Using data compression procedures to prolong data storage, depending when the failure occurs, keep only certain data, discard the rest, try restarting memory |
| **Recovery** | Recovery is not possible during the mission |

**5.12 Risk ID M-E09.**

5.5.2.3 Electrical In-Flight Risks

For the mission phase, the following risks have been identified about the MAIM Payload in the Electrical Subsystem:

| | |
|---|---|
| **ID** | M - E11 |
| **Name** | Malfunction of power electronic of reeling motor |
| **Description** | The H-bridge itself or logic circuitry of power electronic of reeling motor stop working |
| **Consequences** | The experiment has to be stopped |
| **Severity** | 4 |
| **Probability** | 2 |
| **Total Risk** | 8 |
| **Prevention** | Using components for power electronic exceeding the maximal current by the factor of 2 |
| **Reaction** | Activation of emergency reeling system |
| **Recovery** | Recovery is not possible during the mission |

**5.13 Risk ID M-E11.**

The main areas that have been assessed as a high potential risks are the PCB and the Batteries. If the PCB is broken during the implementation and construction of the circuit board then it will take a month for another one to come in hence delaying the project by this amount. How reduce this risk is to make sure that the PCB is safe at all times and no dangerous activities are conducted near it. For safely risks there is a potential that the batteries will self destroy if they are deeply

discharged or overcharged numerous times. The stop this from occurring the PCM has been implemented. For an operational failure there is a potential that the batteries will fail. This system has been made redundant via the use of batteries connected in parallel with every battery having a fuse (poly switch).

### 5.5.3 Software Subsystem Risk Management

#### 5.5.3.1 Software In Flight Risks

For the mission phase, the following risks have been identified about the FISH payload in the Software Subsystem:

| | |
|---|---|
| **ID** | M - S 01 |
| **Name** | Total Software crash |
| **Description** | Program in one (or both) microcontroller fails |
| **Consequences** | If FISH controller fails:<br>- No scientific sensor data<br>- Not possible to prove microgravity -> mission failed<br>- Reeling process not affected -> no increased risk for people on the ground<br>If payload controller fails:<br>- No data at all<br>- Reeling not possible<br>- If in free-fall mode: Loss of FISH (Dangerous!) |
| **Severity** | 5 |
| **Probability** | 1 |
| **Total Risk** | 5 |
| **Prevention** | “Watchdog” checks microcontroller for software crashes and resets it if necessary. A well defined “Power-on-reset” sequence brings the system into a defined safe state (see software design) |
| **Reaction** | Implementation of “watchdog” and “power-on-reset” |
| **Recovery** | Full recovery |

| | |
|---|---|
| **ID** | M - S 02 |
| **Name** | Loss of electrical power |
| **Description** | One (or both) microcontroller(s) fail to operate |
| **Consequences** | If FISH controller fails:<br>- No scientific sensor data<br>- Not possible to prove microgravity -> mission failed<br>- Reeling process not affected -> no increased risk for people on the ground<br>If payload controller fails:<br>- No data at all<br>- Reeling not possible<br>- If in free-fall mode: Loss of FISH (Dangerous!) |
| **Severity** | 5 |
| **Probability** | 2 |
| **Total Risk** | 10 |
| **Prevention** | Cannot be prevented from software site. But for low power situations “Brown-out” detection is implemented. This avoids unexpected behaviour of the microcontroller if supply voltage drops below design limit. |
| **Reaction** | Brown-out detection with controlled shutdown |
| **Recovery** | Not possible to recover |

| | |
|---|---|
| **ID** | I - S 01 |
| **Name** | Wrong program version flashed to microcontroller |
| **Description** | The controller contains an outdated version of the operating software and was not updated before the launch |
| **Consequences** | Unwanted behaviour of experiment. Possible loss of parts of the sensor data or even complete failure of mission |
| **Severity** | 5 |
| **Probability** | 3 |
| **Total Risk** | 15 |
| **Prevention** | Typical human error. Has to be avoided at all costs |
| **Reaction** | Detailed “before launch checklist” |
| **Recovery** | Full recovery if checklist is used |

| | |
|---|---|
| **ID** | M - S 03 |
| **Name** | Loss of communication FISH - payload |
| **Description** | ZigBee connection fails |
| **Consequences** | - Scientific sensor data from FISH cannot be transferred to payload (and ground station).<br>- Sensor data is stored in FISH instead<br>- Control sensor data (GPS) cannot be used for reel up process or backup |
| **Severity** | 4 |
| **Probability** | 4 |
| **Total Risk** | 16 |
| **Prevention** | Use of a simple transfer protocol |
| **Reaction** | Implementation of memory in FISH for sensor data storage |
| **Recovery** | Fully recovered |

| | |
|---|---|
| **ID** | M - S 04 |
| **Name** | Loss of communication payload - ground station |
| **Description** | E-link connection fails |
| **Consequences** | - scientific sensor data cannot be transferred to ground during flight<br>- status information is not available on ground during flight<br>- experiment procedure cannot be altered from ground |
| **Severity** | 3 |
| **Probability** | 3 |
| **Total Risk** | 9 |
| **Prevention** | By default, the experiment is carried out by an automatic sequence that is independent from any ground station commands. All sensor data is stored in the payload |
| **Reaction** | Implementation of an automatic sequencer |
| **Recovery** | Fully recovered |

| | |
|---|---|
| **ID** | M - S 05 |
| **Name** | Payload: Loss of reel speed sensor information |
| **Description** | The speed of the reel cannot be detected any more (nil or faulty data) |
| **Consequences** | Experiment cannot be carried out: Contingency mode (see software design) |
| **Severity** | 5 |
| **Probability** | 2 |
| **Total Risk** | 10 |
| **Prevention** | Not possible to be prevented by software (see Electrical) |
| **Reaction** | Implementation of a backup reel-up procedure where the GPS altitude from the FISH is used for reel speed information (working FISH-payload communication link, working FISH controller and a working GPS are necessary) |
| **Recovery** | Partially recovered (reduced performance) |

| | |
|---|---|
| **ID** | M - S 06 |
| **Name** | Payload: Loss of bail position sensor information |
| **Description** | The position of the bail (open/closed) cannot be detected (nil or faulty data) |
| **Consequences** | Not possible to detect if in freefall mode or slow reel mode |
| **Severity** | 3 |
| **Probability** | 2 |
| **Total Risk** | 6 |
| **Prevention** | Not possible to be prevented by software (see Electrical) |
| **Reaction** | Implementation of a backup bail position detector procedure which detects the movement of the FISH from GPS altitude data. If bail is open: acceleration, If bail closed and reel motor stopped: no movement or deceleration |
| **Recovery** | Partially recovered (reduced performance) |

| | |
|---|---|
| **ID** | M - S 07 |
| **Name** | Payload: Loss of reel motor position sensor |
| **Description** | The movement of the reel motor cannot be detected any more |
| **Consequences** | Slow reel experiment and reel up cannot be controlled |
| **Severity** | 4 |
| **Probability** | 2 |
| **Total Risk** | 8 |
| **Prevention** | Not possible to be prevented by software (see Electrical) |
| **Reaction** | Usage of GPS altitude information to derive reel motor movement |
| **Recovery** | Partially recovered (reduced performance) |

| | |
|---|---|
| **ID** | M - S 08 |
| **Name** | FISH: Loss of accelerometer and/or gyro sensor information |
| **Description** | One or more values of the inertial sensor platform are not valid |
| **Consequences** | Primary objective of experiment cannot be reached (measurement of microgravity) |
| **Severity** | 5 |
| **Probability** | 2 |
| **Total Risk** | 10 |
| **Prevention** | Not possible to be prevented by software (see Electrical) |
| **Reaction** | If only one axis fails, it should still be possible to extract a reduced set of data for post processing |
| **Recovery** | Partially recovered (reduced performance) |

In summary, the most severe risk from the software subsystem point of view is a permanent power loss of one of the two microprocessors. In order to avoid this from happening, the power supply to both microcontrollers is designed to be dual redundant. Even in the rare event that both power supplies fail to operate the microcontroller will shut down in a pre defined manner.

# 6 OUTREACH PROGRAMME

reel.SMRT has a heavy focus on presenting the work during and after completion of the BEXUS high altitude launch to promote awareness and interest in the project and the REXUSBEXUS Program.

Already, two presentations have been conducted at schools in Australia (39) (40); both were well received and had large audiences.

Future presentations have been confirmed at IRV (41) and Rymdgymnasiet (42) in Kiruna as well as for the International Space University's Space Studies Program (43) at the NASA Ames Research Centre in California, USA.

The team is both hindered and blessed by the dispersion of the SpaceMasters (43) involved. Already, three of the team members are based in Japan, Finland and Germany with the remaining six in Kiruna. The six in Kiruna will spread throughout Europe from October 2009. This allows reel.SMRT to present at universities in a number of countries and this will be explored further close to and after the launch.

A large component of the outreach program for the local community of Kiruna is a promotional dinner to be held in the town, with many representatives from business, education and other interested parties to be invited. This will be an opportunity for the team to involve the community and engage them in both a formal and novel context, as well as fundraise for the mission.

0.5 kg have been tentatively allocated to the mass budget. reel.SMRT plans to utilise this volume for outreach activities such as sending letters and small items to the stratosphere for fundraising and outreach.

A review of the web page (44) is to be conducted after the completion of the PDR with inclusion of details from this document and making the site more friendly to the casual browser. An update plan is also being worked on to ensure that the website develops further and important information is added.

Newspapers and periodicals are to be contacted closer to the launch date. Already organised is an article in "Fishing Australia"(45).

# 7 LAUNCH CAMPAIGN

This section encompasses all tasks to be performed and requests for resources during the launch campaign. This includes launch preparation activities, activities during the countdown, experiment time events during the flight, operational data management concept and the preliminary FRP inputs. Furthermore, actions on recovery and post flight activities are presented.

## 7.1 Experiment preparation

Experiment preparation activities that shall be conducted during the launch campaign prior to the gondola launch, are presented here.

The mechanical subsystem shall require a square (preferred) or circular hole to be cut in the floor of the gondola, of 370-5mm x 370-5mm or 370mm – 375mm dia. dimensions respectively. The mechanical subsystem shall then attach the main structure to the gondola by bolting the attachment points on the base of the MAIN Payload onto the gondola floor.

The electrical subsystem shall run diagnostic tests on the battery voltages and the components in both the MAIN Payload and the FISH. This shall be comprised of the motor and sensor function tests. Diagnostics shall be performed using an external power source. Should batteries require charging, they shall be charged using this external power source. The LEDs indicating internal performance as situated on the exterior of the payload shall also be checked for correct operation.

The software subsystem shall connect the data cable from the reel.SMRT payload to the E-Link connection on the Gondola bus. The internal FISH- MAIN Payload communication shall be tested along with the interface to the E-link antenna.

Once these tasks are complete, system tests shall be run. These shall comprise operating the reel and line guide through the microcontroller controls and communication systems and ensuring correct feedback through the system.

Finally, the software version on each microcontroller shall be confirmed to be correct by the software subsystem. The SD cards shall also be confirmed as correctly installed and secure.

The mechanical subsystem shall then ensure that all mechanical switches are fastened to the correct position and locked in place. The mechanical subsystem shall then also confirm that the gondola is secure and shall visually inspect the internal structure of the MAIN Payload to ensure no obstructions are in place. All objects with ‘remove before flight tags’ shall be removed at this stage.

The implementation of these tasks shall be visually confirmed and marked on the reel.SMRT pre-launch checklist by the reel.SMRT Student Payload Manager (student member of the reel.SMRT team). This checklist shall include such actions as positioning ‘remove before flight’ tags in pre-marked areas on desk. The

reel.SMRT Student Payload Manager shall also conduct a rehearsal of this checklist with the responsible members.

reel.SMRT COUNTDOWN

BEXUS 8/9 CAMPAIGN 2009

| RT2 | FROM | TO | REEL.SMRT | Item# |
|---|---|---|---|---|
| -1H | RS M | OP | “REMOVE BEFORE FLIGHT” TAGS | 10 |
| | RS M | OP | POWER ON EXPERIMENT | 20 |
| | RS M | RS PO | CONFIRM POWER ON INDICATOR LIGHTS | 30 |
| | RS M | RS PO | RETURN TAGS TO PAYLOAD OPERATIONS | 40 |
| -45M | RS PO | RS M | COMMUNICATION TEST AND DIAGNOSTICS RUN | 50 |
| | RS M | OP | VISUAL CONFIRMATION OF DIAGNOSTICS | 60 |
| | RS M | RS PO | RETURN TO PAYLOAD OPERATIONS | 70 |
| | RS M | RS PO | CONFIRM CHECKLIST | 80 |
| -30M | RS PO | RS M | PAYLOAD MANAGER CONFIRMATION OF OPERATIONS | 90 |
| | RS PO | SCI | GO/NOGO GIVEN | 100 |

**Table 7.1 reel.SMRT Countdown List**

RS M (reelSMRT Mechanical)

RS PO (reelSMRT Payload Operations)

## 7.2 Experiment Time Events during flight

The experiment shall start recording data as it is awoken from Power Safe mode. The experiment shall stop recording data once it is powered down following the final drop test and the line lock being applied. During the flight, a minimum of 15 drops and 3 slow reels shall be performed. The first mode shall be a slow reel mode to ensure the safe operation of all involved components.

## 7.3 Operational Data management concept

All sensor data generated during the experiment shall be stored locally on SD-Card flash memory. In addition, all data is also downloaded to the ground station to save the data in case the balloon cannot be recovered.

The data rate from the FISH to the MAIN Payload is greatest during the drop tests. During that time it can reach up to 180 kBit/s. The data rate of the downlink to the ground station will never reach a value of more than 20 kBit/s.

The ground station software is directly connected to the balloon transmission system (E-Link) via Ethernet. It provides status and sensor data so that the current state of the experiment can be seen at all times during the flight. In addition, all data downlinked from the balloon shall be stored in a database on the hard drive of the Ground station PC for post-processing. It is possible to transmit telecommands from the ground station to the experiment in case an unforeseen event occurs. By sending certain telecommands, the experiment can recover from a temporary malfunction and continue the flight without a degraded experiment.

The data handling may be realized in a more complicated way if it is necessary. However, by storing the most important sensor data three times, the probability of a total loss of the most precious data remains very low.

## 7.4 Flight Readiness Review - FRR

Reel.SMRT has the advantage of constructing the experiment in Kiruna and will have the benefit of being able to bring the experiment before the flight campaign to integrate and test systems. This allows reel.SMRT to be fully prepared when it comes time to pass the FRR.

## 7.5 Mission Interference Test – MIT

The MIT is of importance to reel.SMRT as not only do EMC effects need to be investigated but so also does the communication between the MAIN Payload and the FISH. The prime function of this test shall be to ensure that there is no interference with the balloon systems but this will also be a good opportunity to test the intra-experiment communication.

## 7.6 Launch Readiness Review – LRR

The launch readiness review will be conducted following the FRR and MIT to examine the readiness of the experiment to begin the launch.

## 7.7 Inputs for the Flight Requirement Plan - FRP

*Dimensions and Mass of Experiment Components*
400*400*800mm
16.5 kg preliminary estimate (possibly up to 20 kg)

*Possible Identified Risks*
Refer to Section 5.5.
All critical risks identified have been mitigated.
Parachute is still to be finalised.

*Electrical Interface*
The only electrical interface of reel.SMRT is the E-LINK connector.

*Power Consumption*
Power is supplied by the experiment system.
Fish: ~0.9W.
MAIN Payload: ~72W.

*Telemetry (Downlink, Uplink)*
Downlink and uplink using the E-Link system are required for experiment control.

*Special Requirements (Experiment preparation, calibration, tests)*
reel.SMRT requires late access to the balloon gondola to allow for testing.

*Timeline for mission preparation and post mission activities*
Delivery - Early September (by car from Kiruna)
Integration - Early September
On Site Testing - Launch week
Returning of Experiment - End of launch week (by car to Kiruna)

### 7.7.1 Requirements on laboratories

Reel.SMRT does not require laboratory access.

### 7.7.2 Requirements on integration hall

The team requests tables and chairs as sufficient for each of the nine members of the reel.SMRT team to work in the integration hall. Access to power and the internet are also required for the project.

### 7.7.3 Requirements on trunk cabling

There are currently no requirements on trunk cabling.

### 7.7.4 Requirements on launcher

reel.SMRT is able to be located anywhere on the gondola but the preference is to be located in the centre to reduce perturbations induced on the experiment.

### 7.7.5 Requirements on blockhouse

Within the blockhouse, the team shall require an area for mission control of the reel.SMRT payload. This shall be comprised of:

1. Two stations for laptops (team's own laptops), including power points. One laptop comprises the primary ground station, the second shall comprise the back-up ground station.

2. As the ground station is used for uplink of commands and downlink of requested telemetry data, the team also requests access to relevant reel.SMRT data downlinked from the balloon and also the capability to uplink to the balloon from these computers.

3. Desk space and seating for seven further team members in close proximity to the ground station.

### 7.7.6 Requirements on scientific centre

There are currently no requirements on the scientific centre.

### 7.7.7 Requirements on countdown (CD)

reel.SMRT requires the E-Link connection during countdown to run diagnostic tests on the system. In order to confirm these tests and conduct other important tasks, the team requires late access to the payload as detailed in the countdown list (see Table 7.1 reel.SMRT Countdown List).

### 7.7.8 List of hazardous materials

Potentially hazardous materials that shall be flown on the reel.SMRT payload include:

1. Batteries
2. Parachute deployment mechanism (potential to have pyrotechnics)

There are no further explosives, radioactive sources or hazardous chemicals present on the reel.SMRT Payload.

### 7.7.9 Requirements on recovery

The recovery procedure required is of the 'normal' mode. Special requirements exist for the purpose of retaining access to data and data integrity and to minimise damage to the hardware.

The requirements include:
1. All hardware of the payload is requested to be returned. The components of highest priority are the SD Cards of the FISH and MAIN Payload.
2. The line connecting the FISH and reel should be cut using scissors or another sharp instrument. The line should then be secured within the structure by a knot being tied to any structural element of the MAIN Payload. The FISH should then be transported carefully to ensure there is no damage. The purpose of this procedure is to minimise the damage to the payload caused by the FISH impacting within the reel.SMRT MAIN Payload or with other experiments.

### 7.7.10 Consumables to be supplied by ESRANGE

There are currently no requests for consumables to be supplied by ESRANGE.

### 7.7.11 Requirement on box storage

It is requested that the reel.SMRT Payload be stored upright and with care as a 'fragile item'. This is to minimise the FISH impacting upon the internal structure and tangling of the tether. The payload should also be stored in a cool (approximately room temperature), dry, indoor area. The approximate volume of the box shall be 0.5m x 0.5m x 1m, with the longest dimension being in the vertical direction.

### 7.7.12 Arrangement of rental cars & mobile phones

Each team member shall carry their own mobile telephone and therefore there is no need for additional mobile phone to be provided. Prior to the launch week, a contact list shall be distributed to the team by the Project Manager including the phone numbers of all relevant personnel.

If any members of the reel.SMRT team are unable to be accommodated at ESRANGE during the launch campaign, rental cars may be required during the for the transportation from Kiruna, if no public transport is readily available. This request shall be confirmed at a later date.

### 7.7.13 Arrangement of office accommodation

There is currently no necessity for the arrangement of office accommodation.

## 7.8 Post Flight Activities

Preliminary analysis will be conducted by Mark Fittock during and after the flight using software developed for this task. This will be to examine the quality of the reduced gravity environment.

After the payload is returned to the cathedral, the SD cards containing the data will be recovered by the member responsible for the data, Jan Speidel, under supervision of the Project Manager. Jan Speidel shall then compare to the data transmitted over the E-Link connection.

The MAIN Payload, FISH and all other equipment will be returned to Kiruna by car at the end of the week by Jan Speidel and Nawarat Termtanasombat.

Following the return to Kiruna, Nawarat Termtanasombat will update the simulation model that is developed. The team will conduct a detailed analysis of the data to determine the performance of the system in relation to the reduced gravity environment. Once these tasks have been completed, the team shall on review the performance of the project and produce the final report.

# 8 EXPERIMENT REPORT

**Not Yet Applicable**

**I. Launch campaign**

1. Flight preparation during launch campaign
2. Flight performance
3. Recovery (Condition of experiment)
4. Post flight activities / operations

**II. Results**

1. Technical and scientific results
2. Outlook

**III. Outreach Activities**

**IV. Lessons learned**

# 9 CONCLUSION AND FUTURE WORK

As reel.SMRT finalises the PDR, it is important to review the progress and plan for the work that is to be conducted before the CDR.

Management will work on refining the schedule and planning for the construction and testing, in addition to monitoring team progress and interfaces. Ongoing tasks such as facilitating communication between team members and outside contacts remain important. The organisation and maintenance of documentation shall also continue to be a paramount task.

Outreach has begun already with two presentations at schools in Australia. Focus will be on the promotional dinner and soliciting organisations for sponsorship. Outreach will expand before the launch with more presentations, updates to the web page and articles in periodicals.

Mechanical will begin construction following the PDR panel and have committed to a number of tests to be conducted during the construction phase. Following the construction will be to begin interfacing with the electronics subsystem and begin the system tests.

Electronics must finalise the design with specific components. Test boards will be constructed so that the software subsystem can begin work on the programming. Following this, construction of the two electronic systems will occur in Kiruna (MAIN Payload) and Helsinki (FISH).

Software will begin programming for the ground station, MAIN Payload and FISH using the test boards. Once the electronics and mechanical systems have been constructed and assembled, the software may be implemented and full system testing can begin.

reel.SMRT plans to deliver the experiment to Esrange in July where preliminary communication tests and confirmation of attachment applicability can be examined.

The reel.SMRT team ‘reely’ look forward to launching the experiment in October and then following this up with analysis and outreach. reel.SMRT is committed to producing a top quality experiment and is thankful for the opportunity that has been provided.

# 10 ABBREVIATIONS AND REFERENCES

## 10.1 Abbreviations

| | |
|---|---|
| AC | Aerodynamic Centre |
| AIT | Assembly, Integration and Test |
| ASAP | As soon as possible |
| BO | Bonn, DLR, German Space Agency |
| BR | Bremen, DLR Institute of Space Systems |
| BSD | Berkeley Software Distribution |
| CAD | Computer Aided Design |
| CDR | Critical Design Review |
| CoG | Centre of Gravity |
| DC | Direct Current |
| DLR | Deutsches Zentrum für Luft- und Raumfahrt |
| EAT | Experiment Acceptance Test |
| EAR | Experiment Acceptance Review |
| EBASS | Balloon Piloting System |
| EGon | ESRANGE Balloon Gondola |
| EIT | Electrical Interface Test |
| E-Link | Ethernet up & downlink system |
| EMC | Electro-Magnetic Compatibility |
| EPM | ESRANGE Project Manager |
| ESA | European Space Agency |
| ESRANGE | European Sounding Rocket Launching Range |
| ESTEC | European Space Research and Technology Centre, ESA |
| ESW | Experiment Selection Workshop |
| FAR | Flight Acceptance Review |
| FEA | Finite Element Analysis |
| FISH | Free-falling Instrument System Housing |
| FS | Factor of Safety |
| FST | Flight Simulation Test |
| FRP | Flight Requirement Plan |
| FRR | Flight Readiness Review |
| GNU | GNU's Not Unix |
| GPS | Global Positioning System |
| GSE | Ground Support Equipment |
| HARVE | High-Altitude Reduced-Gravity Vehicle Experiments |
| HK | House Keeping |
| H/W | Hardware |
| ICD | Interface control document |
| I/F | Interface |
| IRF | Institutionen för Rymdfysik |
| IRV | Institutionen för Rymdvetenskap |

| | |
|---|---|
| LT | Local Time |
| LOS | Line of Sight |
| LTU | Luleå Tekniska Universitet |
| LRR | Launch Readiness Review |
| Mbps | Mega Bits per second |
| MFH | Mission Flight Handbook |
| MORABA | Mobile Raketen Basis (DLR, Eurolaunch) |
| MTR | Mid Term Report |
| NYA | Not Yet Applicable |
| ODE | Open Dynamic Engine |
| OP | Oberpfaffenhofen, DLR Center |
| PDR | Preliminary Design Review |
| PFR | Post Flight Report |
| PST | Payload System Test |
| RTOS | Real Time Operating System |
| SDK | Software Development Kit |
| SED | Student Experiment Documentation |
| SM | Spacemaster |
| SMRT | SpaceMaster Robotics Team |
| SNSB | Swedish National Space Board |
| SSC | Swedish Space Corporation (Eurolaunch) |
| STW | Student Training Week |
| S/W | Software |
| T | Time before and after launch noted with + or - |
| TBC | To be confirmed |
| TBD | To be determined |
| TKK | Teknillinen Korkeakoulu |
| UHMWPE | Ultra-High Molecular Weight Polyethylene |
| xgravler | Experimental Gravity Research with Lego-Based Robotic |

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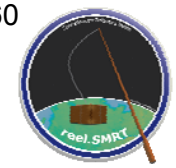
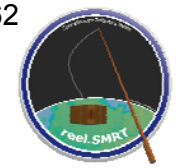

reel.SMRT

# 12 APPENDIX

Attached Document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